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Greenhouse Gas Assessment Handbook

A Practical Guidance Document for the Assessment of Project-level Greenhouse Gas Emissions

September 1998

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The World Bank

Global Environment Division

Greenhouse Gas Assessment Handbook

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Glossary of Terms

a	annum
ALGAS	Asia Least-Cost Greenhouse Gas Abatement Study
C	Carbon
CAI	Current Annual Increment
CH_4	Methane
CFC	Chloroflourocarbons
CO	Carbon Monoxide
CO_2	Carbon Dioxide
dbh	diameter breast height (DBH)
FAO	Food and Agriculture Organization (of the United Nations)
GEF	Global Environment Facility
GHG	greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
MAI	Mean Annual Increment
mc	moisture content
mcdb	moisture content dry basis
mcwb	moisture content wet basis
N	Nitrogen
NO	Nitric oxide
NO_2	Nitrogen oxide
No_x	the sum of NO and NO_2
N_20	Nitrous oxide
NPP	Net Primary Production
OECD	Organization for Economic Cooperation and Development
P	Phosphorus
pH	Hydrogen ion concentration
t	metric tonne
UN	United Nations
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
WB	The World Bank
wt	weight
yr	year

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Executive Summary

The *Greenhouse Gas Assessment Handbook* is designed to provide World Bank staff with a reference manual for estimating the net impact on greenhouse gas (GHG) emissions or sinks that result from the implementation of World Bank supported projects. The estimation of the net impact on GHG emissions or sinks is a necessary element in World Bank project analysis. Most World Bank member countries are Parties to the United Nations Framework Convention on Climate Change (UNFCCC) which, *inter alia*, commits these nations to inventory their anthropogenic GHG emissions and sinks and integrate climate change considerations into development planning. The Handbook provides analysts with a consistent, internationally recognized methodology to prepare estimates of project related impacts on GHG emissions and sinks. It is based on the latest information available from the Intergovernmental Panel on Climate Change (IPCC) and other relevant sources. **The Handbook is designed to assist World Bank Task Managers and analysts to quickly and easily estimate project-associated GHG impacts.**

Most development projects include activities that impact GHG emissions or sinks. The majority of these activities can be divided into two major categories: energy-related and non-energy related. Energy-related activities consist of the production, conversion, distribution and final use of energy products such as fuel and electricity, which result in GHG emissions. Non-energy activities include: forestry, agriculture, industry and waste-disposal activities that impact GHG emissions and sinks. While it is difficult to detail the procedures for conducting GHG assessments for every conceivable World Bank project, the Handbook presents a general set of GHG estimation equations for the categories of projects that dominate the World Bank's lending portfolios. It focuses precisely on the types of World Bank projects where changes in project design can have the greatest influence on project GHG emissions.

The Handbook complements other World Bank environmental assessment guidelines, most notably the *Guidelines for Climate Change Global Overlays*, which provide a sectoral perspective on the integration of GHG emissions into World Bank activities. While the *Guidelines* document takes a macro or sectoral approach, the *Greenhouse Gas Assessment Handbook* is concerned with the project-level estimation of the direct and indirect changes in GHG emissions or sinks associated with an on-going or planned development project.

A straight forward estimation approach is used throughout the Handbook, common to the approach employed in other World Bank economic and technical assessment documents. If the analyst is faced with simply documenting the GHG emissions from a project, then he or she may proceed through a set of basic equations as outlined in the Handbook. If on the other hand, the analyst is being requested or desires to compare the GHG emissions from different project options, the analyst uses the typical World Bank project assessment approach that assumes a **with or without project analysis framework.**

In the case of estimating GHG emissions resulting from various project options, the establishment of the "with" versus the "without" project analysis framework draws on general terminology and methodologies approved by the Intergovernmental Panel on Climate Change (IPCC), which is to establish a **Reference Scenario (without project option)** and the **Mitigation or Alternative Project Scenario (with project option).** The *Guidelines for Climate Change Global Overlays* makes two further important distinctions in defining the reference scenarios, which result in the following set of potential project assessment frameworks:

- **the Reference or Business as Usual Scenario:** the project a country would have undertaken without technical or financial World Bank intervention;

- **the World Bank Proposal or Economic Efficient Scenario**: the World Bank project that optimizes economic efficiency but does not necessarily seek to minimize GHG emissions as an objective; and,

- **the Mitigation or Alternative GHG Minimization Scenario:** the project which matches the benefits of the proposed World Bank project and also has an objective of cost-effectively minimizing the associated GHG emissions.

The Handbook is organized to lead the analyst through the basic steps and concepts necessary to conduct a GHG assessment of each possible scenario. It is organized as follows:

- **Chapter 1 - Introduction (Purpose, Organization and Use)**
- **Chapter 2 - Basic Principles of GHG Accounting**
- **Chapter 3 - Energy Project Assessment Methodology**
- **Chapter 4 - Industry and Infrastructure Project Assessment Methodology**
- **Chapter 5 - Land-Use Project Assessment Methodology**
- **Annexes**

Underlying the Handbook's equations and case studies is a database on GHG emissions by technology, location, and performance. As the information related to climate change is evolving, this Handbook relies on the latest information collected by the IPCC and other scientists throughout the world. One can expect that with increasing country level analysis and better diagnostic tools, estimates for specific coefficients will change over time. Technology performance characteristics, default emission data and other variables are summarized in the annexes for ease of reference and use so that these sections may be changed as the science of climate change evolves.

1 Introduction

1.1 Purpose

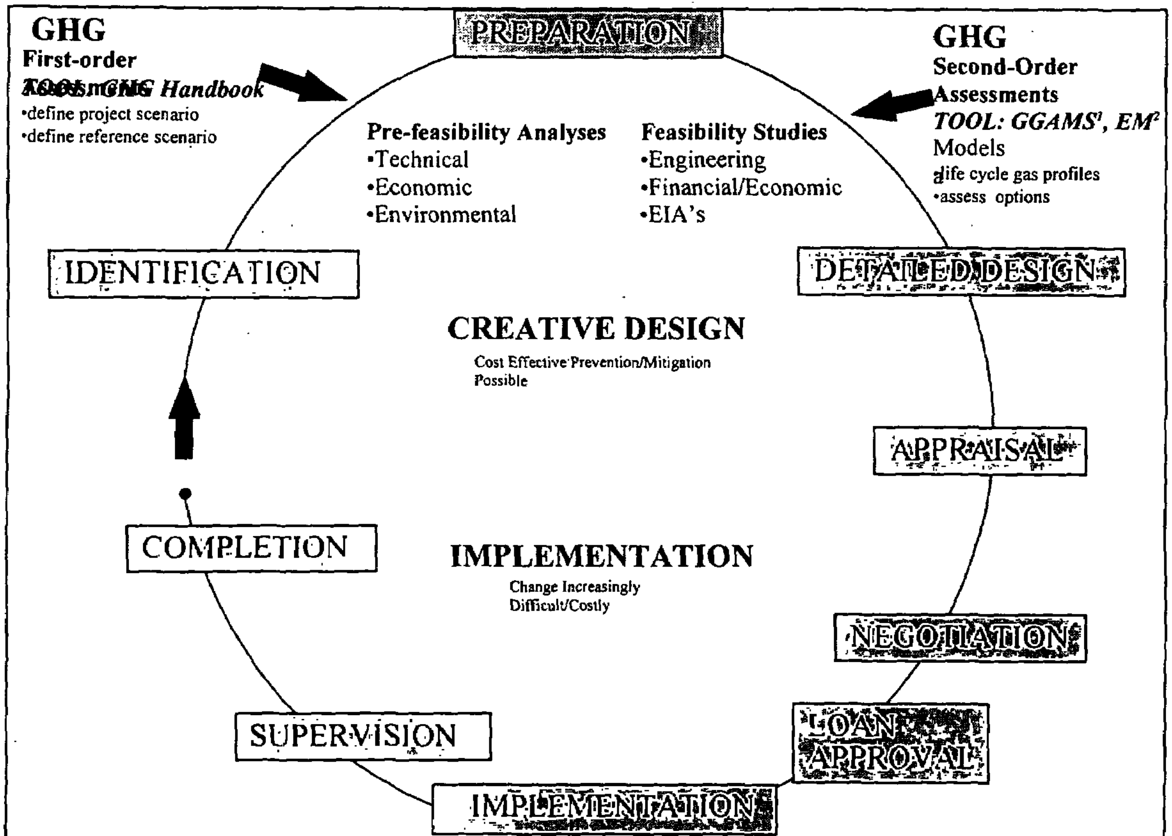
Over 150 countries are Parties to the United Nations' Framework Convention on Climate Change (UNFCCC), which establishes a global objective to inventory and, in the case of many signatory countries, to voluntarily reduce human-induced greenhouse gas emissions. As supporters of the UNFCCC, the World Bank and its sister organizations are committed to ensuring that their activities are consistent with the Convention. Most World Bank member countries are Party to the Convention, therefore the World Bank, *inter alia,* seeks to assist member countries in meeting their commitments under the Convention.

Along these lines, the primary goal of the *Greenhouse Gas Assessment Handbook* is to facilitate and standardize the methodology for assessing the net greenhouse gas (GHG) emissions associated with development projects under consideration by the World Bank. The Handbook is, therefore, designed to provide the project analysts with a set of diagnostic tools to quickly and easily make first-order analyses and comparisons, where appropriate, of a project's GHG emissions.

The assessment methodology described in this Handbook fits readily into the World Bank's project analysis cycle (see Exhibit 1-1). The Handbook is designed to help the analyst be responsive to World Bank Operational Policies (OP10.04, OD4.01) which require global environmental externalities be included into the project analysis cycle. The Handbook provides a set of simplified, step-wise calculations that are consistent with the widely accepted Intergovernmental Panel on Climate Change (IPCC) GHG inventory methodology. Along with the GHG estimation techniques, the Handbook also provides the necessary data for making these calculations. As such, the manual represents a practical extension and application of existing World Bank environmental assessment procedures, with a focus on the project analyst's needs for evaluating the GHG emissions of proposed projects.

It is anticipated that the World Bank project analyst will apply the GHG impact assessment methodology after a first order project design and economic analyses have been conducted. It is expected that, although a full project feasibility study may not yet have been completed, the project will have been characterized to such an extent that key parameters needed for calculating GHG impacts will be known (e.g., fuel consumption patterns, land-use changes, etc.). Integration of GHG considerations into the project cycle at an early stage may save the analyst from spending an inordinate effort on high-GHG emission projects that may be tabled later in the World Bank selection process in favor of a project that provides equal economic and social gains but lower or neutral GHG impacts.

Exhibit 1-1
GHG Assessment Role in Project Cycle



[1] *Greenhouse Gas Assessment Methodology*, 1994.
[2] *Environmental Manual*, 1997.

1.2 Organization

The Handbook is organized to provide the reader with a sequential process of the basic principles, estimation methods and data necessary for conducting GHG assessments of the major categories of projects that have GHG impacts. The Handbook contains the following chapters:

- **Chapter 1 - Introduction (Purpose, Organization and Use);**
- **Chapter 2 - Basic Principles of GHG Accounting;**
- **Chapter 3 - Energy Project Assessment Methodology;**
- **Chapter 4 - Industry and Infrastructure Project Assessment Methodology;**
- **Chapter 5 - Land-Use Project Assessment Methodology; and,**
- **Annexes**

Chapter 1 outlines the purpose, organization, and relevancy of this Handbook. Chapter 2 gives an overview of greenhouse gas sources and sinks, with a discussion of key terms and principles used in GHG emissions and sinks accounting. This chapter lays the conceptual foundation for the final three chapters which present the project-specific GHG assessment methodologies. It describes how the Handbook may be used for assessing a stand-alone project's GHG impacts and how to conduct a comparative analysis of projects by using the "twinning" approach to estimate the net changes in GHG emissions of alternative projects under consideration by a country and the World Bank. This comparative analysis approach allows for the comparison of a "reference case" (the "business-as-usual" or "without" project scenario) versus an alternative (possibly mitigation) project scenario.

Chapters 3, 4, and 5 present the estimation equations, default and country specific data for key GHG variables by project types in the energy, industry, infrastructure and land-use sectors. Chapter 3 describes the methodology for assessing the GHG impacts of energy sector projects. Chapter 4 presents estimation tools for assessing GHG impacts in infrastructure and industry projects. And, Chapter 5 covers GHG impact assessment techniques for land-use projects, including projects in forestry, agriculture, and land management. In each of these final chapters, the analyst is led through a generic set of GHG estimation procedures, with attention later to the nuances particular to the project type. Illustrative applications and example calculations are provided throughout to demonstrate the use of these estimation techniques. The Annexes at the end of the Handbook present general conversion factors and greater detail on a variety of topics.

1.3 Types of World Bank Projects Covered by this Handbook

The World Bank's lending categories for projects addressed in this Handbook are broadly divided into the energy, infrastructure and industry, and land-use sectors. Estimation methods are given for projects that fall in the following areas:

Energy Projects

Energy Resource Exploration and Refinery/Processing Projects

- oil and gas exploration and production;
- coal field development and coal mine productivity improvements;
- gas pipeline construction and upgrading;
- oil refinery construction or improvement;
- coal-bed methane recovery;

Energy Conversion and Distribution

- conventional power generation from resources such as coal, oil and gas;
- non-conventional electricity projects that employ resources such as solar, wind, hydro, biomass, geothermal and landfill gas;
- transmission and distribution extensions and improvements;

Energy Efficiency and Conservation

- improvements in the efficiency of energy production, distribution and use;
- improvements in energy end-use efficiency;

Transport

- energy-related GHG impacts of road, rail, air, and ship transport;

Industry and Infrastructure Projects

- infrastructure projects that have major GHG impacts due to their energy use;
- industrial processes that produce significant GHG emissions, i.e. cement and fertilizer production;

Land-Use and Other Related Projects

- forestry projects that either add to or reduce the GHG storage capabilities of the respective forests (e.g., improved forest management, conservation, plantation);

- arable and pastoral agricultural productivity improvement projects; and,
- soil conservation and watershed management projects that preserve and enhance the land's ability to absorb and fix carbon and nitrogen, respectively.

1.4 Handbook Audience

The Handbook is designed for use by World Bank project analysts, Task Managers, and all other project analysts involved with conducting project pre-feasibility and feasibility assessments. The document provides "rules of thumb" for first-order estimation of GHG impacts. It also allows analysts to easily determine the need for further environmental assessments of GHG emission or sink impacts from projects under consideration by the World Bank.

1.5 Relation to Other Climate Change and World Bank GHG Assessment Documents

The methodological approach presented in the Handbook follows the procedures outlined by the Intergovernmental Panel on Climate Change (IPCC) for conducting GHG inventories (UNEP/OECD/IEA/IPCC 1995) and previously used in various World Bank documents (Mintzer et. al. 1994, World Bank 1994, World Bank 1997a, and the *Guidelines for Climate Change Global Overlays,* World Bank 1997b). Exhibit 1-2 provides more information on the IPCC and the GHG impact assessment methodology.

This Handbook is drafted specifically to assist the World Bank project analyst in conducting micro-level or "bottom-up" **project-based assessments** of GHG emission or sink impacts. In contrast, the World Bank's *Guidelines for Climate Change Global Overlays* (World Bank 1997b) describes the sectoral-level assessment of the GHG impacts of World Bank sectoral lending. This *GHG Assessment Handbook* addresses the GHG impacts of **projects** within different World Bank lending categories. The primary distinction is that the *Guidelines for Climate Change Global Overlays* uses aggregate level data to assess national GHG impacts while this Handbook focuses on project-specific impacts.

This Handbook also is consistent with the World Bank's 1994 document entitled *Greenhouse Gas Assessment Methodology* (commonly referred to as *GGAM*), which assessed the greenhouse gas impacts of projects proposed to the Global Environment Facility (GEF). Like *GGAM,* this Handbook permits an analyst to make both:

- **a stand-alone project analysis,** which is a GHG impact assessment of a single project; or,

- **a comparative project analysis (Reference vs. Alternative projects),** which is referred to in the climate change literature as a "twinning" approach. This approach is similar to a World Bank economist's "with or without" project analysis approach.

This Handbook is compatible with the World Bank's *Greenhouse Gas Abatement Investment Project Monitoring & Evaluation Guidelines,* a 1994 document that provides guidance to World Bank consultants charged with monitoring and evaluating the greenhouse gas impacts of GEF-funded projects. Many of the concepts and methods used here were also employed in the *Monitoring & Evaluation Guidelines*; the main difference between the two documents is that this Handbook is designed to help World Bank managers calculate *ex ante* the expected impacts of proposed projects, while the earlier document was designed to ensure that existing projects were meeting their GHG mitigation objectives.

1.6 GHG Impact Assessment: A Closer Look

Underlying the Handbook's equations and case studies is a rich database of information on GHG emissions by technology, location, and performance. As climate change is an evolving science, this Handbook relies, like other climate change documents, on values collected by the IPCC and other scientists throughout the world.

Exhibit 1-2
The Intergovernmental Panel on Climate Change (IPCC)
Guidelines for National GHG Inventories

Signing of the U.N. Framework Convention on Climate Change (UNFCCC) 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 GHGs 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. This methodology serves as the basis for many of the calculations presented in this Handbook.

Source: UNEP/OECD/IEA/IPCC (United Nations Environment Programme, Organisation for Economic Co-operation and Development, International Energy Agency, Intergovernmental Panel on Climate Change). 1995 *IPCC Guidelines for National GHG Inventories Volume 3: GHG Inventory Reference Manual.* IPCC: Bracknell, UK. This exhibit also appears in *Guidelines for Climate Change Global Overlays* (World Bank 1997b).

One can expect that with increasing country level analysis and better diagnostic tools the values for specific data will change over time. For this reason, the Handbook presents, in the accompanying tables and annexes, a range of estimates for many variables so that an analyst may select the most appropriate information for a given situation. Technology performance characteristics, default emission data and other variables are summarized in the annexes for ease of reference and use so that these chapters may be changed as better information becomes available.

Finally, this document is designed to serve as an analytical tool for World Bank staff and client country counterparts. It supplies techniques for estimating one type of environmental externality: greenhouse gas emissions. It simply leads a project analyst through the procedures of quantifying the net impacts on GHG emissions and sinks of a specific project.

References

UNEP/OECD/IEA/IPCC (United Nations Environment Programme, Organisation for Economic Co-operation and Development, International Energy Agency, Intergovernmental Panel on Climate Change). 1995. *IPCC Guidelines for National GHG Inventories Volume 3: GHG Inventory Reference Manual.* IPCC: Bracknell, UK.

Mintzer, Irving, Stan Kolar, and D. Von Hippel. World Bank. 1994. *Greenhouse Gas Assessment Methodology (GGAM)* Environment Department. Washington, DC.

World Bank. 1994. *Greenhouse Gas Abatement Investment Project Monitoring & Evaluation Guidelines.* Environment Department. Washington, DC.

World Bank. 1997b. *Guidelines for Climate Change Global Overlays.* Environment Department. Washington, D.C.

2 Basic Principles of Greenhouse Gas Accounting

The purpose of this chapter is to provide the project analyst with background information regarding global climate change science and policy, and to explain the basic concepts and principles of GHG accounting and impact assessment methodology that are applied in this Handbook.

2.1 Anthropogenic GHGs and the Risk of Global Climate Change

The most recent report of the Intergovernmental Panel on Climate Change (IPCC) found that "the balance of evidence suggests a discernible human influence on climate" (IPCC 1996). The IPCC's report indicates that an increase in the mean global temperature of 2°C over the next century is likely, potentially resulting in a sea level rise of as much as one meter, increased inundation of coastal areas, higher frequency of flooding and more intense storms.

The IPCC has identified the emissions of greenhouse gases (GHGs) from human activities as a primary cause for global climate change. The primary anthropogenic (human-induced) GHGs include:

- carbon dioxide (CO_2);
- methane (CH_4);
- nitrous oxide (N_2O);
- a variety of manufactured aerosols that do not occur in nature, primarily chlorofluorocarbons (CFCs);
- ozone (O_3)[1];
- carbon monoxide (CO);
- non-methane hydrocarbons (NMHCs); and
- nitrogen oxides (NO_x).

Exhibit 2-1 depicts the relative contribution to global radiative forcing of these gases, showing that carbon dioxide CO_2 is the largest contributor to "radiative forcing," followed by methane and then nitrous oxide. The exhibit does not include CFC-11 and CFC-12. Together the three primary GHGs (CO_2, CH_4 and N_2O) account for over 90 percent of GHG emissions, while the remaining gases make relatively small contributions.

Exhibit 2-2 presents the human activities that cause the GHGs covered under the United Nations Framework Convention on Climate Change (UNFCCC). CFCs are not shown, because these ozone-depleting chemicals are regulated by the Montreal Protocol rather than the UNFCCC. The exhibit shows that the primary sources of anthropogenic GHGs are:

- **Consumption of fossil fuels** to provide electricity, heat and steam to the industrial, commercial and residential sectors, and to fuel the transportation sector. The combustion of fossil fuels produces carbon dioxide and small amounts of other GHGs. In addition, the production and transport of fossil fuels result in methane leakages from coal mines and natural gas pipelines, which also contribute to the atmospheric build-up of GHGs;

- **Land-Use changes**, principally deforestation, which releases the carbon dioxide stored in forest organic matter and soils;

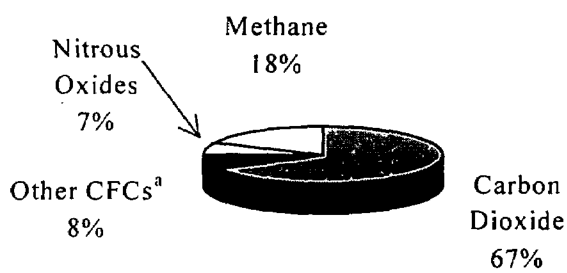
- **Agriculture**, the principal contributions of which are methane emissions from rice cultivation and livestock, nitrous oxide emissions from fertilizer, and CO_2 emissions from vehicles and processing equipment used in agricultural activities;

- **Cement manufacturing**, which involves chemical processes which result in CO_2 emissions; and

- **Landfills and sewage treatment**, which emit methane to the atmosphere.

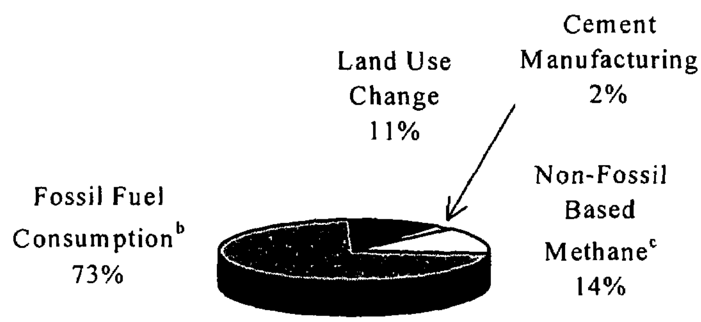
This Handbook will address all of the above categories, presenting formulas and data for them.

Exhibit 2-1
Greenhouse Gas Emissions by Relative Contribution to Global Radiative Forcing
(1991)



Source: Global Environment Facility, 1995.
a. Include CFCs other than CFCs 11 and 12.

Exhibit 2-2
Sources of Greenhouse Gas Emissions Covered Under the UNFCCC, 1991[a]



Source: Carbon Dioxide Information Analysis Center, 1995.
a. Greenhouse gas emissions covered under the UNFCCC do not include CFCs.
b. Fossil fuel consumption includes the global warming potential of methane from oil and gas production, and coal mining.
c. Non-fossil based methane includes solid waste, wet rice, agriculture and livestock.

2.2 An Overview of GHG Impact Assessment Methodology

The typical steps taken in conducting GHG project assessments are outlined in Exhibit 2-3. Chapters 3, 4 and 5, which cover project applications, present the procedures for undertaking the first three steps presented in Exhibit 2-3. The fourth and fifth steps of the exhibit are not described in detail in this Handbook. This is because they require the analyst to consider economic, institutional, social and local environmental project impacts, as well as GHG impacts. Note that Exhibit 2-3 is not meant to imply that GHG impacts must be assessed before other considerations may be made.

The approach outlined in Exhibit 2-3, which may be described as "twinning", is to compare the GHG impacts of the project that is of interest to the practitioner (known as the **Alternative Project** case) to those of a **Reference Project** case, which generally may be described as the activity that would have taken place if the project were not undertaken. This straightforward estimation approach is consistent with approaches employed in other World Bank economic and technical assessment documents. Note that if instead of comparing a project to a reference (case) scenario the analyst simply desires to document the GHG emissions from a project, then the analyst will still find the equations presented in the Handbook to be useful.

Exhibit 2-3
Methodological Approach for GHG Project Assessments

Assessment Steps
Step 1: Develop Estimate of Reference Project Case GHG Emissions ("What Would Have Happened in the Absence of the Project")
Step 2: Develop Estimate of Alternative Project Case GHG Emissions
Step 3: Determine Difference Between Reference and Alternative Project GHG Emissions
Step 4: Develop Economic and Other Project Analysis
Step 5: Identify and Propose Least-cost, Least-GHG Project Option(s)
Adapted from: World Bank, *Guidelines for Climate Change Global Overlays*, 1997b.

In a **Comparative Analysis Approach,** the Alternative Project case referred to in Exhibit 2-3 is simply the project that the analyst is investigating. The Reference Project scenario refers to the action that most likely would have been undertaken in the absence of the Alternative Project. It may be defined more precisely in one of the following three ways:

1. **Reference Project:** The action or actions that most likely would be undertaken in the absence of *any* World Bank-supported activity. This reference case, which was described in *Guidelines for Climate Change Global Overlays* as the "Reference" or "Business-as-Usual" scenario, is developed based on expected economic, social and environmental conditions in the country or region of study. For example, if the World Bank is contemplating the development of new electricity generating resources in a particular country, and that country's energy expansion strategy calls almost exclusively for the development of new coal-fired power plants, the coal-fired generation would represent the Reference Project case.

2. **World Bank Proposed Economic Efficient Project:** The project that the World Bank itself most likely would take if the Alternative Project were not undertaken and assuming that GHG emission reductions or sink enhancement impacts were not an objective. This reference case may also be thought of as the least-cost option for meeting a particular objective, subject to the environmental criteria and other laws in place in the target country. This definition of the Reference case is referred to in *Guidelines for Climate Change Global Overlays* as the "Bank Reform" or "Economic Efficient" scenario.
3. **Alternative Least-Cost, Low GHG Project Option:** The project option that could be proposed by the World Bank that both minimizes GHG emissions (or maximizes GHG sinks) and maximizes the socio-economic welfare of the country. Note that *Guidelines for Climate Change Global Overlays* also refers to this case as a "Mitigation" or "Low Carbon" scenario, defined as the activity that would result in lower GHG emissions than the Reference scenario.

The choice between the two definitions of the Reference case (numbers 1 and 2) will influence the GHG impacts of the project being evaluated, because in many cases the project host country would not be able to adopt the World Bank Proposed project option without World Bank assistance. There is no right answer as to whether the Task Manager should define the Reference case as the Business-as-Usual or World Bank Proposed scenario; he or she should decide based on the circumstances governing the particular situation.

If the Task Manager feels that the World Bank will take some action but has not decided what it will be, then the World Bank Proposed scenario may be the appropriate choice of Reference case. On the other hand, if the World Bank seeks to investigate the viability of the development of a particular resource rather than more generally the opportunities available in a given sector (such as energy or agriculture), then the Business-as-Usual scenario may be more appropriate. For instance, if a World Bank country initiative were dedicated solely to the exploration and development of biomass use for power generation rather than to power generation capacity development in general, then it is likely that no World Bank-supported electricity project development would occur in the absence of the biomass initiative. The Business-as-Usual scenario would therefore be the proper choice of the Reference case.

Once the Reference and Alternative Project cases have been defined, the analyst is ready to apply the GHG impact assessment methodologies described in Chapters 3, 4, and 5, which are adapted from the framework employed by the *IPCC Guidelines for National GHG Inventories*. GHG impact assessment methods vary from sector to sector and from project to project within a sector; nevertheless, they may be described in general terms on a sector basis, as follows:

- **Energy Sector**: Assessment of the GHG impacts of energy projects generally involves the comparison of expected emissions from the Project and Reference scenarios, which in turn are a function of the amounts and types of fuel used in the projects, and the carbon dioxide emissions (per unit of energy) associated with these fuels. High carbon fossil fuels such as coal and oil are often the least-cost energy choice, and as such will represent the Reference Project option. In contrast, energy efficiency measures and renewable energy resources such as wind and solar power may be more expensive and/or capital intensive, though in some cases they will represent the economically efficient option. Coal and oil produces relatively high GHG emissions per unit of energy output, while the combustion of natural gas results in fewer GHGs, and renewable energy resources result in even lower or no GHGs. Projects in which fossil fuel use is defined as the Reference Project scenario and natural gas or renewable energy use represents the Alternative Project case therefore normally will result in a reduction in greenhouse gases.

- **Infrastructure and Industry**: Infrastructure and industry projects may involve GHG impacts. For example, a transport project could change the amount of fossil fuels consumed for a given transport service (i.e., rail freight replacing truck freight) resulting in a GHG "impact." Alternately, an infrastructure project such as a port facility or large bridge could also have a significant component of "embodied energy". However, a project analyst needs to be careful not to double count the GHG impacts of embodied energy as these impacts are best accounted for directly at the point of energy use. If the impacts of embodied energy are to be accounted for in large infrastructure projects, then the project analyst must carefully define the project boundaries to include the use of the embodied energy. In addition, several industrial processes -- notably cement and fertilizer production -- involve the emission of significant GHGs. Therefore, World Bank projects that involve cement or fertilizer manufacture should be carefully evaluated.

- **Land-Use - Forestry Sector**: The GHG impacts of projects in this sector, which include projects to grow biomass for conservation or use, will depend primarily on the amount of carbon stored (or "sequestered") over time in the biomass. GHG benefits are principally a function of the number of hectares dedicated to biomass growth, the carbon storage potential of the species planted (as well as the soils in which they are planted), harvesting schedules and project duration.

- **Land-Use - Agriculture Sector**: It is difficult to generalize about the methodologies used to calculate agriculture sector project GHG impacts, because projects in this sector vary significantly in nature. Two of the major sources of GHG emissions from the agriculture sector are: (a) methane emissions from wet rice agriculture; and (b) methane emissions from livestock. Methods to assess the GHG impacts from these two agricultural activities are outlined by the IPCC and can be used to assess the impacts of World Bank projects in these areas. Other agricultural activities are not as significant in producing GHG impacts and as such may not require detailed analysis for GHG impacts.

2.3 Principles of GHG Impact Assessment Used in this Handbook

Embedded in the methodologies presented in this Handbook are numerous greenhouse gas accounting principles and energy measurements (Annexes 1 and 2). Several of these are now discussed below.

2.3.1 Activities that Produce GHG Emissions

Almost all World Bank projects will in some way or another have an impact on GHG emissions. In the interest of focusing attention on the areas where it is most due, the methodology presented in this document takes into consideration the GHG impacts of projects in the major GHG-producing sectors only. These include:

- **Energy**: Chapter 3 addresses carbon dioxide and methane emissions associated with all stages of the energy cycle, from resource extraction to end use.
- **Industry**: Chapter 4 provides methodology for calculating both the energy- and non-energy-related GHG emissions from industrial projects in areas such as hard rock mine development, steel production and equipment manufacturing.
- **Infrastructure**: Chapter 4 also will be useful to Task Managers addressing the GHG emissions from projects in areas such as transportation, water and sewage, ports and landfills.
- **Land-Use (Forestry** and **Agriculture)**: Chapter 5 discusses the GHG impacts of projects in these sectors.

Exhibit 2-2 suggests that because their projects may have significant GHG impacts, Task Managers working on projects in the above areas may need to address the GHG impacts of their projects, while analysts and managers in areas such as public health and education probably need not. This focus on the major emitting sectors is consistent with the methodology used by the IPCC and other World Bank climate change documents such as *GGAM* and *Guidelines for Climate Change Global Overlays*.

2.3.2 Gases Included

The methodology provided in the following chapters addresses the impacts of World Bank projects on emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), while other gases for the most part are ignored. This is because the three primary gases account for nearly all of the greenhouse effect, as presented in Exhibit 2-1. The IPCC methodology also addresses only these three major gases (UNEP/OECD/IEA/IPCC, 1995).

2.3.3 Level of Detail

In many cases it will not be feasible or practical for the analyst to identify and quantify all of the GHG emissions impacts of a particular project. Where the analyst has access to a model that does allow for full inclusion, such as the *Environmental Manual* (World Bank 1997a) that assesses the GHG impacts of power projects, then such a model should be used. In many other situations, however, the analyst may instead want to use this Handbook to focus on the primary GHG emissions that fall within project boundaries. (See the discussion of project boundaries below.) A useful general rule (also applied in *GGAM*) is to ignore any impact that appears to be less than ten percent of the greatest GHG impact associated with the project. The analyst may first have to make a "back-of-the-envelope" calculation based on the data and methodologies presented here to quickly determine whether or not a particular impact appears to be material. Application of this rule would mean, for example, that the analyst could ignore methane emissions related to fossil fuel combustion, because these emissions are insignificant relative to the carbon dioxide emissions from the same combustion process.

2.3.4 Global Warming Potential

To compare the climate change impacts of various gases, the scientific community developed the concept of **Global Warming Potential (GWP)**, which allows one to express all GHGs on a comparable basis. The strength of all other greenhouse gases is compared to that of carbon dioxide, which is assigned a value of "1." Exhibit 2-4 presents the most recent GWPs developed for the major gases, while Annex 3 presents more comprehensive information about the entire range of GHGs.

Consistent with the IPCC approach, this Handbook refers to the 100-year time horizon GWPs in assessing project GHG emissions impacts. On a tonne-for-tonne basis, then, methane is assumed to be 21 times more powerful than CO_2 in trapping heat, while N_20 is assumed to be 310 times more powerful (see Annex 3). The IPCC regularly publishes new estimates of GWPs, as new information alters our understanding of the relative heat-trapping strength of the various GHGs. Exhibit 2-5 provides information on how to stay apprised of the latest developments in climate change science.

2.3.5 System Boundaries and GHG Accounting

The GHG emissions accountable to a particular project are those that fall within that project's boundaries. A variety of different terms and conventions may be used to define these boundaries. One approach is to categorize emissions as either **on-site** or **off-site**. The essence of this approach is **geography.** Emissions that take place at a project site are of course considered on- site, while those that result from activity elsewhere are considered off-site. Classifying emissions in this way is simple but not complete.

A more comprehensive approach is to account for all significant emissions related to a project, whether they take place on-site or off-site. In energy analysis, this is known as the **total fuel cycle** or **full energy supply cycle** approach. Under such "**full cycle**" accounting, the material impacts of activities that relate to the project activity but occur before or after it are taken into account. These are known as **upstream** and **downstream** project impacts.

In a project that involves energy conversion, upstream emissions include GHGs related to fuel recovery, processing and distribution. For example, in a project to improve efficiency and reduce energy use at a steel mill, an upstream GHG impact would be the reduction in methane released at the underground coal mine from which the coal used in the steel mill was mined. Another example from a non-energy sector project would be the emissions from the gasoline or diesel used to carry saplings to a reforestation project. Upstream impacts also include **embodied** (or **embedded**) **emissions**, which result from the making of a product employed in the project. An example of embodied emissions is the carbon dioxide resulting from the manufacturing of concrete employed in a World Bank infrastructure project. An example of a downstream indirect impact would be an increase in natural gas use by small industries in an area as a result of a World Bank-supported project to build a natural gas pipeline to serve a particular electricity generation plant in that same area.

Exhibit 2-4
Direct Global Warming Potentials (GWP) of Selected Greenhouse Gases

Gases	Chemical Formula	Atmospheric Lifetime	Direct Effect for Time Horizons of: 20 years	100 years	500 years
Carbon dioxide	CO_2	(a)	1	1	1
Methane (b)	CH_4	14.5+/- 2.5 (c)	56	21	6.5
Nitrous Oxide	N_2O	120	280	310	170

(a) decay of CO_2 is a complex function of the carbon cycle.
(b) Includes 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.
(c) Represents adjustment time rather than atmospheric 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 (UNEP/OECD/IEA/IPCC, 1997.) This exhibit was taken from *Guidelines for Climate Change Global Overlays* (World Bank 1997b) and updated to reflect IPCC 1997.

While the full cycle approach is comprehensive and theoretically rigorous, its application is fraught with problems. First, it may be quite difficult and very time-consuming to accurately quantify certain upstream or downstream emissions. For example, consider an industrial project that employs steel. If the electricity used in producing the steel was generated using coal, then the GHGs embedded in the steel may be significant; on the other hand, if the steel were produced with hydroelectric power, then there would be low embedded emissions. [2] The World Bank project analyst is unlikely to have the time or the information needed to accurately estimate such impacts.

Another problem with full cycle accounting is that it may easily lead to the double- counting of GHG impacts. For instance, assume that both the coal-fired power plant producing electricity and the steel mill using that electricity were World Bank-supported projects. If both entities account for the power-related GHG impacts, this would result in double-counting of GHG impacts.

Because on-site accounting is too simple and full cycle accounting too onerous, we have chosen to take a common sense, hybrid approach to defining project boundaries. **The approach taken here is to allow Task Managers and analysts to define project GHG boundaries themselves, based on the reasons that the projects are undertaken.** This approach has the dual advantages of reasonable accuracy and ease of use. In some cases, boundaries may be defined to include on-site activities only, while in other cases, boundaries may be drawn to include upstream or downstream activities as well. Of course, if an analyst is comparing two or more similar projects, the boundaries for all of the projects must be defined in the same way so that the GHG impact analysis is not biased for or against certain projects.

Some examples will help to illustrate ways in which project GHG boundaries may be drawn. Assume that the World Bank will be supporting a project to construct a new diesel-fired power plant. Calculating the GHG impacts of this project would be straightforward, involving an estimation of the carbon dioxide from the combustion of diesel used at the plant. Another simple example: Assume that the World Bank plans to fund the reforestation of land that has been converted to agricultural use. In this case, the major GHG-related activity would be the uptake of carbon resulting from tree growth. In addition, if data were readily available and the impact were thought to be significant, the analyst could compute the CO_2 emissions associated with transport of new trees to and at the project site.

Exhibit 2-5
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/

Source: This exhibit first appeared in *Guidelines for Climate Changes Global Overlays* (World Bank 1997b.)

Finally, consider a World Bank-funded project to improve the transmission of electricity from a fossil fuel-fired power plant to a nearby town. In this case again, project boundaries would be drawn to look past the transmission wires themselves to the power plant, because the purpose of the project would be not to reduce transmission losses for their own sake but to reduce the amount of electricity (and fuel) needed to serve the town. By defining the project boundaries in this way, the analyst's GHG accounting would (properly) show that the project would result in a reduction in GHG emissions, even though it did not directly involve the combustion of fuel.

2.3.6 Comparing Project GHG Impacts

As noted above other climate change-related documents circulating in the World Bank give great attention to defining a "Reference" case, or the activity that would have been undertaken had the project being evaluated not been realized. For instance, *Guidelines for Climate Change Global Overlays* (World Bank 1997b) states that a project may be compared to a "Reference" or "Business-as-Usual" scenario, which is the action or actions that most likely would be undertaken in the absence of any World Bank-supported activity; to a "Bank Reform" or "Economic Efficient" scenario, which is the project that the World Bank itself most likely would undertake if the Alternative Project were not undertaken; or to a "Mitigation" or "Low Carbon" scenario, defined as the activity that would result in lower GHG emissions than the Reference scenario. Similarly, the *GGAMs* approach is based on the "twinning" of a project being considered by the GEF with a conventional alternative.

The approach taken in this Handbook is that if a comparative project analysis is required, the analyst should choose as few or as many reference cases as he or she sees fit, based on the circumstances governing the particular situation. The analyst may use the methodology presented to evaluate the impacts of one project, then apply the methodology again to evaluate a second alternative, and so on. The results of each analysis could then be compared.

If the analyst believes that the World Bank will take some action but has not decided what it will be, then he or she may want to use this Handbook to compare several projects to one another. On the other hand, if the World Bank seeks to investigate the viability of employing a particular resource rather than employing standard opportunities in a given sector, then the book is also useful for comparing a project to the activity that the host country would have taken otherwise.

2.3.7 Project Time Horizon

The GHG emissions or sink impacts of a particular project may vary greatly over time. For example, the GHG impacts of a project to capture the methane emissions from a sanitary landfill will decline once the landfill is closed, eventually reaching zero. Comparing the emissions of one project to an alternative for a particular year, therefore, will not necessarily provide an accurate picture of the relative long-run global GHG impacts of the two projects. **For this reason, it is important that the analyst employ the methodologies presented in this Handbook to estimate GHG impacts over the life of the project.**[3]

In many cases it may be difficult to estimate the life of a project *ex ante*. A useful rule, also employed in the *GGAMs* is to use a project's expected economic life as an estimate of the time horizon for future greenhouse gas impacts. While this approach may understate the impacts of projects that operate beyond their expected economic life, it nevertheless provides a useful first order approximation of the emissions time horizon.

2.3.8 GHG Emissions Discounting

Just as with financial and economic flows, GHG impacts over time may be discounted to reflect one's judgment of the relative importance of present vs. future impacts. Choosing a discount rate of zero percent reflects a belief that emissions today are equal in their contribution to climate change to emissions in the future, while the choice of a positive discount rate displays a belief that future emissions are less dangerous than those now. Choice of a negative discount rate demonstrates a belief that future emissions are more dangerous than GHG emissions today.

Because the "damage function" related to GHG emissions is not well-understood, it is difficult to say what the proper rate for discounting GHG emissions should be. This Handbook, while allowing the project analyst to choose a discount rate, recommends a rate of zero percent. This recommendation is consistent with that in the *GGAMs,* model and *Guidelines for Climate Change Global Overlays*. A zero discount rate is the easiest to apply, as the analyst may evaluate GHG impacts over a project's life by simply summing annual project impacts.

Endnotes

[1] Although tropospheric ozone is not emitted directly by humans, its atmospheric concentration is affected by gases emitted directly by human activities.

[2] There are methane emissions arising from the flooding of land due to the construction of hydroelectric dams and reservoirs. Please refer to section 5.5.1.

[3] In some cases, emissions last beyond the life of the project. For example, methane and carbon dioxide continue to be emitted for many years after a landfill has stopped receiving waste.

References

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3 Energy Project Assessment Methodology

3.1 Background

The energy sector is the major source of anthropogenic greenhouse gas emissions, accounting for 73 percent of global GHG emissions in 1991 (see Exhibit 2-2). This situation is a result of the world's dependency on high carbon fossil fuels, in particular coal and oil. Decoupling the services that energy provides from fossil fuel reliance in developed and developing countries is necessary to reduce and eventually reverse the global rate of growth in GHG emissions.

Fossil fuel use and resulting GHG emissions are growing most rapidly in developing countries. This situation must be considered by energy planners and project developers if least-cost environmentally sustainable fuel and technology options are to be utilized in the future. The World Bank has estimated that annual investments of US$100 billion per year are needed in the energy sectors of developing countries alone.

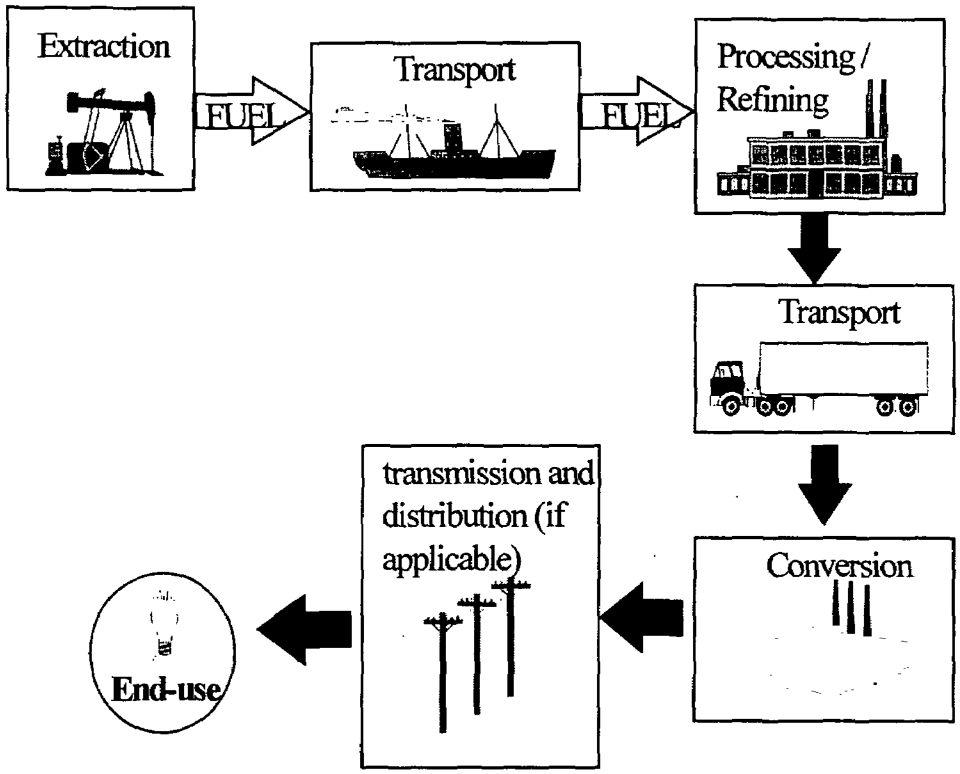
Where the costs of low-GHG energy projects are below or equal to the costs of the Business-as-Usual project options, then these low GHG emissions options should be advocated by the World Bank and client countries to demonstrate a commitment to the objectives of the UNFCCC. In cases where lower-GHG emitting technologies are more expensive than the economically efficient option, World Bank project officers and client countries may seek the assistance of the Global Environment Facility for the funding of project " incremental costs" (i.e., the difference in cost between the economically efficient and low-emissions projects.)

The purpose of this chapter is to present the World Bank analyst with the tools and data needed to assess the GHG emissions associated with the broad diversity of energy sector projects that the World Bank supports. The analyst may also use this chapter to address the GHG impacts of World Bank industrial and infrastructure projects that result in changes in energy use. Of course, the analyst must also address the non-energy GHG impacts of these projects, using the methodology provided in Chapters 4 and 5.

3.2 The Energy Cycle and World Bank Energy Project Types

Exhibit 3-1 presents a diagram of the **full energy supply cycle** or the **total fuel cycle**. The exhibit shows that the cycle begins with the extraction of fuel, then moves to energy processing and refinement, energy conversion and finally to the use of energy services by the energy consumer. As it moves along this path, the energy medium may be physically transported from one stage to another by a variety of technologies and transport systems.

Exhibit 3-1
The Full Energy Supply Cycle



For example, coal may be carried by train to a power plant, crude oil carried by tanker to a refinery, or electricity carried by wire from the power plant to a substation and then to end users.

The World Bank supports project activities in every stage of the energy cycle (including transportation, transmission, and distribution). In some cases, the World Bank will support the development of new facilities, while in other cases it will upgrade or expand existing facilities. Examples of project types at the different stages of the energy cycle include the following:

- **Extraction/production** projects include activities such as oil and gas exploration and production, coal mine development, and geothermal resource development. Similarly, a project to establish a biomass plantation or to collect wood waste for use in power generation would be considered resource production;

- Examples of projects related to energy resource **transportation, transmission and distribution** include the development of a natural gas pipeline, construction of a district heating distribution system, or the upgrade of a power transmission system. Another example would be a project to reduce methane leakages from a natural gas pipeline;

- **Processing and refining** activities include the construction, upgrade of oil refineries or expansion, coal cleaning and drying plants, and biomass fuel processing plants;

- **Energy conversion** activities encompass the conversion of fuels to useful forms of energy. This includes the combustion of fossil fuels to provide heat, steam or shaft power, the conversion of shaft power to electricity or the transformation of solar energy into electricity in a photovoltaic cell; and

- Projects related to **energy end use** include energy conservation, energy efficient appliances, and "demand side management" programs.

Of course, many World Bank energy sector projects involve more than one stage of the energy cycle. For example, the World Bank may support a comprehensive program to develop new electricity generation facilities in a region, while at the same time improving that area's transmission and distribution system and promoting more efficient industrial energy use. Similarly, a World Bank project to develop a "mine-mouth" coal-fired power plant would relate to the extraction (coal mining), processing (coal cleaning and drying), and conversion (power generation) stages.

3.3 GHG Assessment Methodology for Energy Projects

The methodology presented in this chapter may be used to estimate the GHG impacts of any of the types of energy projects just described. It has been adapted from the IPCC methodology to be used for project-level rather than national-level GHG accounting. The approach described is a series of equations that will enable the project analyst to convert the expected fuel use impacts of a project into an estimate of GHG impacts. Key data inputs in these equations include project fuel use, the carbon density and energy content of fuels, GHG emission factors and technology fuel conversion efficiencies. If they are available, the analyst should use project-specific data to estimate these parameters; if they are not available, the default values provided within the Handbook may be used. These values have been derived primarily from the IPCC guidelines, although this source has been supplemented by numerous other GHG accounting reference materials (World Bank 1994a, World Bank 1994b, UNEP/OECD/IEA/IPCC 1995, DOE/EIA 1996).

Because the use of this Handbook should complement rather than precede project pre-feasibility and feasibility studies, it is assumed that World Bank consultants will already have performed some project technical and economic assessments, and therefore have identified and quantified the major fuel consumption impacts of projects. **The analyst therefore should have to gather minimal data to perform the computations described here.**

The methodology for computing the GHG impacts of World Bank energy sector projects consists of the following steps:

- Step 1: Define Project Boundaries
- Step 2: Estimate Project Fuel Consumption Impact
- Step 3: Estimate Carbon Emissions Impact
- Step 4: Estimate Carbon Oxidized during Fuel Conversion
- Step 5: Estimate Total Carbon Dioxide Emissions Impact

These steps refer to the calculation of carbon dioxide only and not to the other major GHGs (methane and nitrous oxide.) The reason is that World Bank projects, for the most part, will not result in significant emissions of these other two gases. The exceptions are underground coal mine projects, which may result in the release of coalbed methane to the atmosphere; oil and gas production, processing and transport activities, which may also result in fugitive methane emissions; and projects involving biomass combustion, which results in emissions of both CH_4 and N_2O. These topics are addressed later in subchapters 3.4 and 3.5. Exhibit 3-2 provides a chart that summarizes the main GHG impacts for projects in the energy sector that the analyst must consider.

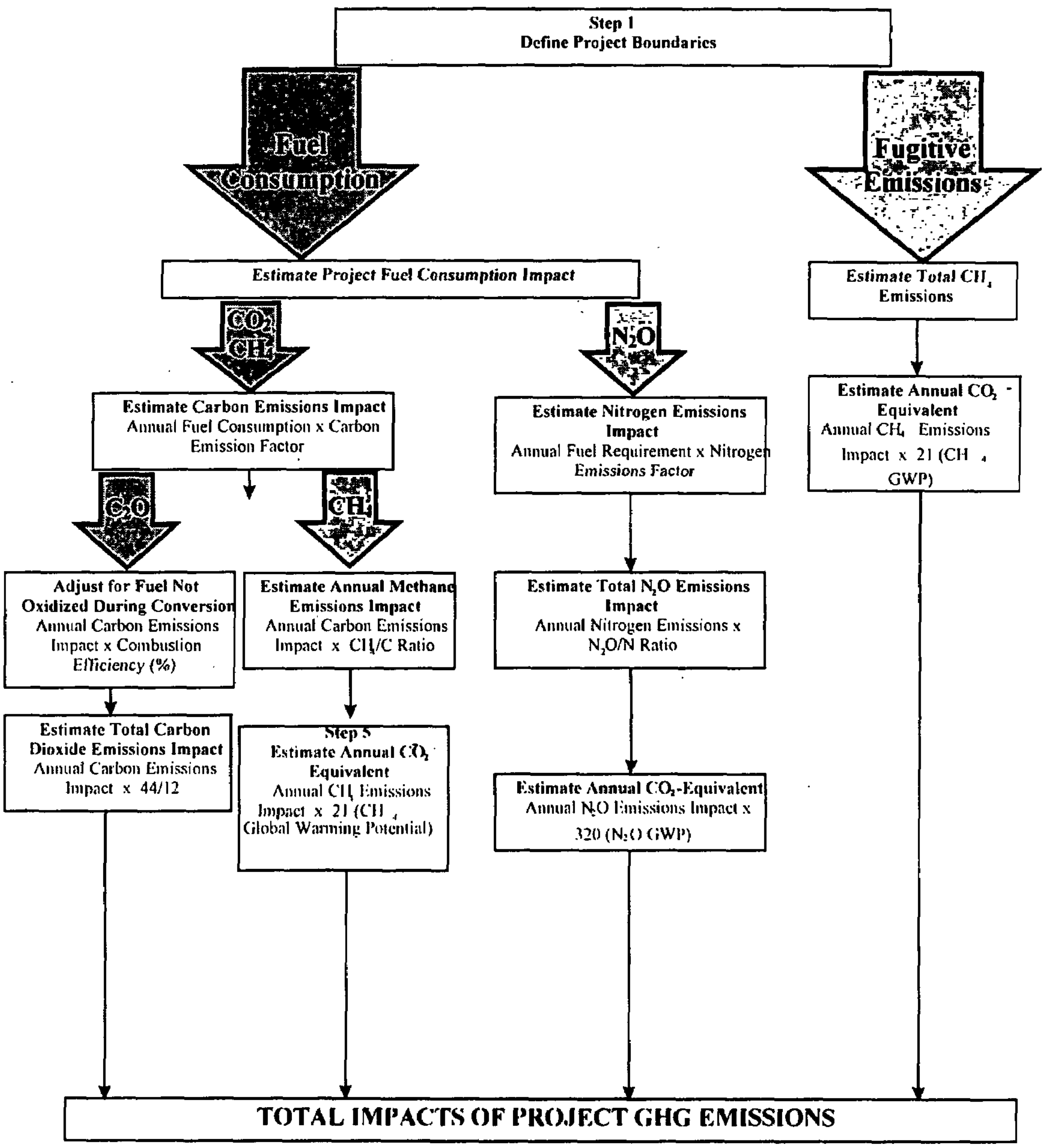
When computing the GHG impacts of any energy project, the analyst must include CO_2 from fuel combustion, fugitive methane emissions, and nitrous oxide and methane from biomass burning. In addition, the analyst must also consider land-use changes. Examples include the clearing of land to make way for a power plant or transmission line or the destruction of forest by strip mining. This type of activity may result in the release of carbon dioxide to the atmosphere.

Step 1: Define Project Boundaries

A critical first step in assessing project GHG impacts is to define the stages of the energy supply cycle involved in the project, because clearly a project's GHG impacts cannot be estimated if the project itself is not well-understood. As discussed in Chapter 4, defining a project's boundaries requires that the analyst refer back to the reasons for undertaking the project. By taking this step the analyst will be able to identify the activities that deserve his or her attention, as well as those that are ancillary to the project's mission. As such, he or she may be able to spend less time and effort on data collection and analysis than would be needed under a "total fuel cycle" approach, without compromising the accuracy of the GHG impact calculation.

An example will help to demonstrate the definition of project boundaries. Consider the case of a project to upgrade an oil refinery so that it could produce more kerosene and diesel, and less residual fuel oil. The purpose of this project is to change the product mix of the plant. One might also argue that a downstream effect of the refinery upgrade is a change in the energy consumption patterns of the country. However, in an economically efficient scenario, the fuels demanded could be supplied either by the refinery upgrade or by imports. Thus, it can be argued that the refinery upgrade is not driving the change in demand but rather the change in demand is driving the refinery upgrade. The analyst therefore should draw the boundaries of the project to include only the "refinery" stage and should exclude the "conversion" stage of the energy cycle (see Exhibit 3-1). The major GHG-related impact of the project thus would be a change in energy used at the refinery.

Exhibit 3-2
Summary of Energy Sector Project GHG Impacts



Step 2: Estimate Project Fuel Consumption Impacts

The second step in assessing an energy sector project's GHG emissions is to estimate the projects fuel consumption impacts. **Fuel type** is one of the most critical determinants of a project's GHG impact, because fuels differ in their carbon contents and therefore in their associated carbon dioxide emissions. Fossil fuels with relatively low carbon-to-hydrogen ratios such as natural gas produce fewer GHGs per unit of energy than heavier fuels such as diesel and coal. Renewable energy resources such as wind and solar power have no direct GHG emissions because they involve no fuel combustion. Sustainably grown (closed-loop) biomass is also considered to be a near zero-GHG fuel, because the carbon dioxide emitted upon the burning of biomass is exactly offset by the carbon dioxide sequestered during plant growth (although secondary products of biomass burning, such as N_2O emissions, do contribute to net GHG emissions; see section 3.5)

In addition to fuel type, **conversion efficiency** is another key determinant of fuel use. This concept, which is normally discussed in power projects, refers to the percentage of energy within a fuel that is transformed into usable energy during the conversion process. It is important that the analyst be consistent in choosing efficiencies and heating values. If the analyst uses the net plant conversion efficiency (which employs High Heating Values), the analyst should employ the High Heating Value in determining the net calorific value in Step 3. If the analyst uses the gross plant conversion efficiency (which employs Low Heating Values), the analyst should employ the Low Heating Value in determining the net calorific value in Step 3. The relationship between a power plant's fuel requirement and its conversion efficiency is as follows:

Formula 3.1 Calculating Annual Power Plant Fuel Requirements

(Annual Plant Electricity Output kWh/yr	x	**Conversion Factor)** 3.6×10^6 J/kWh	/	**(Plant Conversion Efficiency** (%)	x	**Unit Conversion Factor)** 1 TJ/10^{12} J	=	**Annual Plant Fuel Requirement** TJ/yr

Formula 3.1 shows that the higher a plant's conversion efficiency, the less fuel will be needed to produce a given number of kWh. Conventional utility scale power plants normally have net conversion efficiencies (from fuel in to electricity out) ranging from 30 to 35 percent, meaning that they convert approximately one-third of the energy contained in their fuel source (e.g., coal, diesel, natural gas, biomass) into electricity. Some of the more advanced combined-cycle power plants can achieve net conversion efficiencies in excess of 40 percent. Smaller, off-grid power generators normally have lower efficiencies, ranging from 20 to 30 percent. Cogeneration plants are designed to produce electricity and process heat which can be used in industrial processes. The ability to productively utilize a large fraction of the waste heat which would normally be exhausted to the environment allows cogeneration plants to achieve a higher conversion efficiency of fuel to useful energy. As a result, cogeneration plants can approach conversion efficiencies of 80 percent.

The number of kWh that a plant will generate in a year is a function of the plant's annual operational **capacity factor.** A plant's capacity factor is defined as the actual output of the plant divided by the maximum rated output of the plant. Thus, the plant's capacity factor represents a percentage of the maximum or rated output of the plant that is actually achieved by the plant. The capacity factor of a plant can vary due to down time for maintenance, repairs, or even lack of demand for the output of the plant. Typical capacity factors in developed countries for "base load' power plants range of 80 to 85 percent while "peak load" power plants may operate with capacity factors of less than 30 percent. The formula for computing a plant's electricity production when accounting for its capacity factor is:

Formula 3.2 Calculating Annual Electricity Production

Plant Capacity	x	Conversion Factor	x	Annual Hours	x	Plant Capacity Factor	=	Annual Electricity Production
MW		10^3 kW/MW		8,760 h/yr		(%)		kWh/yr

Calculating Power Plant Fuel Requirements: *An Example*: A 150 MW coal-fired power plant is expected to run at an 80 percent capacity factor and a 33% conversion efficiency. The number of kWh produced by this plant in a year would be:

150 MW	x	10^3 kW/MW	x	8,760 h/yr	x	80%	=	1.05×10^9 kWh/yr

The plant's fuel requirement would equal:

1.05×10^9 kWh per year	x	Conversion Factor 3.6×10^6 J/kWh	/	33% (0.33) Conversion Efficiency	x	Conversion Factor 1 TJ/10^{12} J	=	11,467 TJ/yr

When evaluating a project's GHG impacts, it is important to consider the impact on the use of all fuels associated with a project. For instance, assume that the World Bank is planning to fund a project to recover methane from a landfill and then use it as a fuel source in a power plant that is now coal-fired. In evaluating the GHG impacts of the project it would be necessary to estimate the reductions in GHGs resulting from decreased coal use as well as the GHG emissions from the combustion of methane. (In addition, the analyst would account for the benefits of capturing landfill methane that otherwise would have been released to the atmosphere.)

As already noted, it is expected that the analyst will conduct project assessments which include estimates of project fuel consumption. As such, the analyst will have the basic data needed to conduct the project GHG impact assessment.

Step 3: Estimate Carbon Dioxide Emissions Impact

To estimate the carbon dioxide emissions associated with an energy project, one must convert the estimate of the project's fuel use impact into an estimate of carbon dioxide emissions. This is done for each fuel by multiplying fuel use by a "carbon emission factor" or "carbon emission coefficient" for that fuel. The equation is as follows:

Formula 3.3 Calculation of Annual Carbon Dioxide Emission Impact

Carbon Emission Factor	x	Annual Fuel Consumption Impact	=	Annual Carbon Emission Impact
t C/TJ		TJ/yr		t C/yr

Note that to use this formula, the analyst may first need to convert the fuel use impact from Step 2 into terajoules. This is because quantities of energy resources often are expressed in units of mass (e.g., tonnes in the case of coal) or volume (e.g., cubic meters in the case of natural gas.) To convert fuel consumption from units of volume or mass to terajoules, the analyst may apply the following formula:

Formula 3.4 Converting Annual Fuel Consumption to Terajoules

Net Calorific Value	x	Annual Fuel Consumption	=	Annual Fuel Consumption
TJ/ unit of volume or mass		unit of volume or mass		TJ/yr

Net calorific value (NCV) is a measure of the heat content or energy density of a fuel. It often is expressed in terajoules per thousand tonnes (TJ/10^3 tonnes), though the value for natural gas is expressed in TJ/m^3. Exhibit 3-3 presents default values for the NCVs for a range of refined petroleum products, while Annex 4 provides NCVs for coal and oil products, organized by country. Exhibit 3-4 provides representative values from this annex. Exhibit 3-5 presents the default NCVs for a variety of biomass energy fuel sources. **The NCV for pipeline quality natural gas is 3.454 x 10^7 J/m^3.** Applying a default methane density of 670 grams per m^3, this translates into **51.55 TJ/10^3 tonnes**. Annex 5 presents specific gravities for solid liquid and gaseous fuels. The analyst must remember that within a particular fuel type, NCVs may differ considerably according to local conditions. The analyst therefore should use local estimates if available.

Exhibit 3-6 provides default values for the carbon emissions factors for a wide variety of fossil fuels. The default value for renewable energy resources is zero. The table, which first appeared in the IPCC guidelines (UNEP/OECD/IEA/IPCC 1995) shows that carbon emissions factors vary widely across fossil fuel types. Like NCVs, carbon contents within a given fuel type may vary dramatically. Locally derived carbon emissions factors therefore should be used if available. Annex 6 presents default factors for CO_2, CH_4, N_2O, CO and NO_x emissions from utility and industrial combustion systems, organized by fuel and technology type.

Exhibit 3-3
Net Calorific Values for Refined Petroleum Products

Fuel	TJ per 10^3 tonnes
Gasoline (aviation and auto)	44.80
Jet Kerosene	44.59
Other Kerosene	44.75
Gas/Diesel Oil	43.33
Residual Fuel Oil	40.19
LPG	47.31
Ethane	47.49
Naphtha	45.01
Bitumen	40.19
Lubricants	40.19
Petroleum Coke	40.19
Refinery Feedstocks	44.80
Other Oil Products	40.19

Source: OECD/IEA 1993a, as cited in UNEP/OECD/IEA/IPCC 1995.

Exhibit 3-4
Selected Net Calorific Values, by Fuel and Country
$TJ/10^3$ tonnes

Fuel	Chile	India	Russia
Crude Oil	42.91	42.79	42.08
Hard Coal (domestic)	28.43	19.98	18.58
Lignite/sub-bituminous coal (domestic)	17.17	9.80	14.65

Source: OECD/IEA 1993b, as presented in UNEP/OECD/IEA/IPCC 1995.

Exhibit 3-5
Net Calorific Values for Selected Biomass Fuels

Fuel	Moisture Content Wet Basis (%)	Typical Heating Value ($TJ/10^3$ tonnes)
Wood (wet, fresh cut)	40	10.9
Wood (air dry, humid zone)	20	15.5
Wood (air dry, dry zone)	15	6.6
Wood (oven dry)	0	20.0
Charcoal	5	29.0
Bagasse (wet)	50	8.2
Bagasse (air dry)	13	16.2
Coffee husks	12	16.0
Ricehulls (air dry)	9	14.4
Wheat straw	12	15.2
Maize (stalk)	12	14.7
Maize (cobs)	11	15.4
Cotton gin trash	24	11.9
Cotton stalk	12	16.4
Coconut husks	40	9.8
Coconut shells	13	17.9
Dung cakes (dried)	12	12.0

Source: Gowen 1985.

Calculating Carbon Content: An Example: Consider again the 150 MW power plant described in Step 2. Assume that this plant is to be located in India and would burn locally-mined lignite. Using Formula 3.3 and Exhibit 3-6, the analyst could calculate the annual carbon dioxide emissions from this plant to be:

$$\underset{TJ/yr}{11{,}467} \times \underset{t\ C/TJ}{27.6} = \underset{t\ C/yr}{316{,}507}$$

Exhibit 3-6
Average Carbon Content of Selected Fuels

Primary Fuels	**Carbon Content t C/TJ**
Crude Oil	20.0
Natural Gas (dry)	15.3
Natural Gas Liquids	15.2
Anthracite	26.8
Coking Coal	25.8
Other Bituminous Coal	25.8
Sub-bituminous Coal	26.2
Lignite	27.6
Peat	28.9
Secondary Fuels	
Gasoline	18.9
Natural Gas (pure methane) (a)	14.5
Jet Kerosene	19.5
Other Kerosene	19.6
Gas/Diesel Oil	20.2
Residual Fuel Oil	21.1
Liquefied Petroleum Gas	17.2
Ethane	16.8
Naphtha (b)	20.0
Bitumen	22.0
Lubricants (b)	20.0
Petroleum Coke	27.5
Refinery Feedstocks (b)	20.0
Other Oil (b)	20.0
Coke	29.5

Source: UNEP/OECD/IEA/IPCC 1995.
(a) Computed by the authors.
(b)The IPCC did not have access to specific carbon contents values for these fuel types.

Step 4: Estimate Carbon Oxidized during Fuel Conversion

Unless the analyst has factored in a plant conversion efficiency that accommodates fuel conversion losses in Step 2, the analyst must estimate the carbon oxidized during fuel conversion. During the combustion of fossil fuels a small percentage of carbon is not oxidized, or converted to carbon dioxide. The amount of unburned carbon is variable, depending on fuel type, combustion technology, equipment age and operating and maintenance practices. For natural gas, combustion efficiency is normally about 99 percent (corresponding to an un-oxidized fraction of 1 percent) and can reach as high as 99.9 percent. The unburned carbon from coal also sometimes represents about one percent of total carbon, though the percentage may be as high as ten percent. Oil combustion efficiency is normally 98.5 percent, plus or minus one percent (IPCC 1995).

The estimate of project carbon dioxide emissions resulting from Step 3 must be slightly adjusted to account for combustion efficiency. This is done as follows:

Formula 3.5 Adjustment for Incomplete Combustion

"Unadjusted" Carbon Dioxide Emission Impact t C	x	Combustion Efficiency (%)	=	Carbon Dioxide Emission Impact t C

Exhibit 3-7 presents the default combustion efficiencies recommended by the IPCC. Again, however, it should be noted that because of local circumstances, more specific data should be applied if available.

Applying a Combustion Efficiency Factor: An Example: The coal-fired power plant described in Step 3 was predicted to emit approximately 316,500 tonnes of carbon each year. Applying Formula 3.5 and the appropriate default factor from Exhibit 3-7, this figure can be adjusted to:

316,500 t C/yr	x	0.98	=	310,170 t C/yr

Exhibit 3-7
Selected Combustion Efficiency Default Values

Coal (a)	0.98
Oil and Oil Products	0.99
Gas	0.995
Peat for electricity generation (b)	0.99

Source: UNEP/OECD/IEA/IPCC 1995.
(a) This figure is a global average. Actual figures will vary with coal type and combustion technology and can be as low as 0.91.
(b) Peat used in households may be much lower.

Step 5: Estimate Carbon Dioxide Emissions Impact

The final step in estimating GHG impacts is to convert from tonnes of carbon to tonnes of carbon dioxide. This is done by multiplying the carbon impact from Step 4 by the conversion factor of 44/12, which represents the molecular weight of carbon dioxide relative to that of carbon.[1]

Formula 3.6 Calculating Annual Carbon Dioxide Emissions

Annual Carbon Dioxide Emissions Impact t C/yr	x	**Carbon Dioxide/Carbon Conversion Factor** 44/12 t CO_2/t C	=	**Annual Carbon Dioxide Emissions Impact** t CO_2/yr

Example: Annual carbon dioxide emissions from the coal-fired power plant described above would equal:

310,170 t C/yr	x	44/12	=	1,137,290 t CO_2 per year.

Considering All Activities

As already noted, the methodology just presented must be applied for all fuel consumption activities of the project. Total project GHG emissions impacts will equal the sum of the impacts of consumption changes for each activity. For example, for a project that affects fuel use at three power plants the analyst must consider the effects on GHG emissions of fuel use changes at all three plants. Similarly, at a project that changes the mix of fuels at a particular plant the analyst must follow the above methodology for all fuels in the mix.

The entire methodology for calculating the GHG impacts of an energy sector project may be summarized as follows:

Formula 3.7 Summary of GHG Energy Sector Methodology

$$\Sigma_{a,b,c}\ (FC \times C \times O \times 44/12) = \text{Annual GHG Emissions}$$

where: a, b and c are fuel use activities; FC represents annual fuel consumption of a particular activity; and C and O are the carbon emission factor and combustion efficiency, respectively.

Note that in some cases technical experts will provide the analyst with emissions factors that already have oxidation factors and the conversion from C to CO_2 embedded in them. In these cases the analyst must simply multiply the change in fuel consumption from each activity by the appropriate emissions factor.

Projecting Future Years' GHG Emissions

GHG impacts also should be assessed over the economic life of the project. This will be especially important when performing comparative analysis, because projects may have different project lifetimes, or because they may have different emissions impact profiles. For instance, the emissions from a coal mine development project will increase over time as coal production ramps up, while emissions from a project to generate power from coal mine methane will decrease over time as methane capture decreases.

As noted in Chapter 2, future years' GHG emissions impacts may be discounted much the way financial flows are. Choosing an appropriate discount rate is problematic, however, because the relative importance of past, present, and future emissions is not well-understood. This Handbook therefore recommends that the analyst simply sum annual emissions impacts over the life of the project (thereby implicitly choosing a discount rate of zero).

3.4 Fugitive Methane Emissions

Fossil fuel production, processing and transport activities can result in the release of **fugitive methane emissions** to the atmosphere. Activities that may result in such emissions include:

- **Underground coal mining**: These emissions often are vented to the atmosphere, although sometimes they are flared (converted to carbon dioxide through combustion) or used as an energy fuel;

- **Coal processing, transportation and use**;
- **Oil and gas production**, which results in methane leakages from gathering systems;

- **Crude oil transport and refining**: Because methane is a constituent of crude oil, leaks or the venting of unsafe vapors during fuel storage and transport result in atmospheric GHG emissions; and

- **Natural gas processing, transportation, and distribution**: Leakages from natural gas processing plants, transmission pipelines, and distribution systems also represent a source of GHG emissions. Methane is the chief constituent of natural gas; pipeline quality gas is nearly pure methane.

To the extent they are significant and fall within project boundaries, methane emissions from these sources must be counted in project GHG impacts. Fugitive methane emissions therefore should be identified and quantified during project scoping. Assessing the GHG impacts of fugitive methane emissions is a two step process.

Step 1: Estimating the Total Annual Quantity of Methane Emissions

Underground coal mine methane emissions normally are expressed in cubic meters per tonne of coal produced. Especially gassy mines emit as much as 30 m^3/tonne (IPCC 1995), although figures in the range of 10 to 20 m^3/tonne are more common even at gassy, permeable coal seams. Oil and gas-related methane leakages usually are expressed in units of kilograms per petajoule of oil or gas produced (kg/PJ, where one petajoule is equal to 10^{15} joules). Estimates of these leakages vary widely based on local circumstances and the stage of the energy cycle involved. The analyst should therefore rely on project-specific estimates of methane emissions.

It is important to keep in mind that methane emissions from underground coal mines can be captured and then used as fuel. Coalbed methane utilization projects have two GHG impacts that must be considered. These are first, the GHG benefit provided by capturing methane that otherwise would have escaped to the atmosphere; and second, the impact of using coalbed methane to displace a higher-emitting fuel such as coal or oil. To the extent that a coal mine development project will capture and utilize methane, these benefits should be included in the analysis of project GHG impacts.

Similarly, techniques and technologies are available to reduce the methane leakages from fossil fuel production, transport, and processing. For instance, natural gas production and transmission losses may be reduced by replacing the "high bleed" pneumatic devices used to monitor and control gas flow with "lower bleed" devices. Inspection and maintenance (I&M) programs are another way of reducing natural gas system fugitive emissions. These programs employ special vapor analyzing equipment and can be used to identify leaks that need to be stopped (World Bank 1996a). If World Bank funded oil and gas projects include such measures to reduce or capture and utilize fugitive methane emissions, estimates of the GHG impacts of these projects should be reduced accordingly.

Step 2: Converting Methane Emissions to Global Warming Potential (GWP)

Once the analyst has an estimate of the methane emissions associated with a project, this estimate must be multiplied by the global warming potential (GWP) of methane, which is currently considered to be 21. This step is taken to convert the estimate of methane emissions into units of tonnes of carbon dioxide-equivalent (tonnes CO_2-equivalent), so that the ability of these emissions to trap heat in the atmosphere may be compared to that of carbon dioxide. For further discussion of the concept of GWPs, see Chapter 2.

Formula 3.8 Estimation of Annual Fugitive Emissions

Project Fugitive Methane Emissions $t\ CH_4/yr$	x	**Global Warming Potential of Methane** 21 $t\ CO_2$-equivalent/t CH_4	=	**Annual Project Fugitive Methane Emissions** $t\ CO_2$-equivalent/yr

3.5 Methane and Nitrous Oxide Emissions from Biomass Combustion

The combustion of biomass results in the release of carbon dioxide, methane, and nitrous oxide in addition to numerous other GHGs (including non-methane hydrocarbons). As noted earlier in this chapter, the burning of sustainable biomass is considered to have no net impact on carbon dioxide emissions, because the carbon dioxide emitted upon combustion is assumed to be exactly offset by the capture of carbon dioxide during the re-growth of the biomass.

In general, the methane, nitrous oxide, and other GHG emissions associated with biomass projects will be minor compared to those of carbon dioxide; as such, the analyst may choose to ignore them during the first-order assessment of project GHG impacts. It is possible, however, that in some circumstances CH_4 and N_2O emissions could be expected to be significant. The following methodologies are presented for these special cases. It should be noted that the analyst will need data regarding fuel composition to make these calculations. Methane emissions are calculated by applying the following steps:

Step 1: Estimate the Carbon Released by Biomass Combustion

To calculate this, the analyst must know the carbon content (in percentage terms, by weight) of the fuel;

Step 2: Apply a CH_4/C Ratio

Multiply the amount of carbon released by the fraction of this carbon that is expected to be released as methane;

Step 3: Estimate Methane Emissions

Multiply the result from Step 2 by 16/12, which represents the molecular weight of methane relative to carbon; and,

Step 4: Compute to Units of CO_2-Equivalent

Finally, multiply the result from Step 3 by the global warming potential of methane (21) to estimate biomass methane emissions in units of carbon dioxide-equivalent tonnes.

These steps may be summarized as a formula, as follows:

Formula 3.9 Calculating Annual Methane Emissions from Biomass Combustion

Annual Carbon Released t C/yr	x	**% of Carbon to be Released as Methane (%)**	x	**Conversion Factor** 16/12 CH_4/C	x	**Conversion Factor** 21 $t\ CO_2$-equiv/ $t\ CH_4$	=	**Methane Emissions from Biomass Combustion** $t\ CO_2$-equivalent

The steps for calculating nitrous oxide emissions are similar:

Step 1: Estimate the Nitrogen Released by Biomass Combustion

The IPCC notes that for fuelwood this figure is likely to be about one percent of carbon released;

Step 2: Apply the N_2O/N Ratio

Multiply the amount of nitrogen emitted by the fraction that is expected to be released as nitrous oxide rather than NO_x;

Step 3: Estimate Nitrous Oxide emissions

Multiply the result from Step 2 by 44/28, which represents the molecular weight of N_20 relative to nitrogen;

Step 4: Compute to Units of CO_2-Equivalent

Finally, multiply the result from Step 3 by the global warming potential of nitrous oxide (320.) This step converts biomass nitrous oxide emissions into units of carbon dioxide-equivalent tonnes.

Formula 3.10 Calculating Annual Nitrous Oxide Emissions from Biomass Combustion

Annual Nitrogen Released t N/yr	x	**% of Nitrogen to be Released as N_2O** (%)	x	**Conversion Factor** 44/28 N_2O/N	x	**Conversion Factor** 320 t CO_2-equiv/ t N_2O	=	**Annual N_2O Emissions from Biomass Combustion** t CO_2-equivalent/yr

3.6 Project Guidelines and Case Studies

This chapter provides more specific guidance regarding the assessment of energy project GHG impacts and offers four case studies that demonstrate how the analyst would apply the GHG assessment methodologies. Exhibit 3-8 provides a list of the energy project types discussed in this chapter.

Exhibit 3-8
Case Studies of Project Types

Section	Project Type
3.6.1	Energy Extraction
3.6.1	Energy Fuel Processing/Refining
3.6.2	Electricity Generation, Transmission and Distribution
3.6.2	Cogeneration
3.6.3	Transportation
3.6.4	Energy Efficiency

3.6.1 Guidelines for Energy Extraction and Refining Projects

Energy extraction and processing/refining projects can produce or offset GHG emissions in a number of ways:

- Projects to extract energy resources, such as the construction of a coal mine or the development of an oil field, will result in increased energy use and therefore carbon dioxide emissions. In addition, both underground coal mining and oil and gas production may result in fugitive methane emissions. Methane emissions from underground coal mines can be significant, while those from surface mines usually are not. Similarly, methane leakages associated with oil and gas production normally are not substantial. It should also be noted that energy extraction projects may result in GHG emissions from land clearing. For example, surface mining may result in forest destruction and therefore the release of carbon stored in trees and soil.

- Projects to improve the efficiency of energy extraction may result in reduced energy consumption and therefore to lower carbon dioxide emissions.

- The GHG impact of refining/processing projects will vary by project. Projects to construct, upgrade or expand an oil refinery will result in increased energy use and therefore higher CO_2 emissions. A project to refine natural gas to pipeline specifications or to clean coal will also result in greater fuel consumption and increased carbon dioxide emissions; however, these projects may also lead to the displacement of the use of higher carbon fuels and as such may lead to the mitigation of GHG emissions. Whether these downstream impacts are include in the project GHG assessment will depend on how the analyst draws project boundaries. (See the discussion of this topic earlier in this chapter.) Methane leakages may also result from oil refining and natural gas processing projects, although these fugitive emissions generally are not significant.

The following case study provides an example of how to assess the GHG impacts of an oil refinery upgrade project.

Case Study 3-1 - Oil Refinery Upgrade[2]

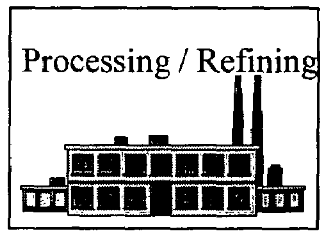
Introduction: This project involves support of an oil refinery upgrade. The project will improve the distilling processes at the refinery, leading to the production of more distillate oil products and less residual oil. The improvements in the distillation process will result in a ten percent increase in energy consumption at the refinery. The fuel source at the plant is petroleum coke produced on-site and the annual energy consumed in distilling is estimated to be two percent of the energy embodied in the oil processed. The plant processes five million tonnes of oil annually (approximately one hundred thousand barrels a day).

Project Summary

Project Type:	Oil Refinery Upgrade
Energy Cycle Stage Involved:	Processing/Refining
Fuel Used:	Petroleum Coke
Project Economic Life:	25 years
Net GHG Impact (CO_2-equivalent tonnes):	Annual GHG emissions are expected to equal 42,835 tonnes; emissions over the life of the project will be 1,070,873 tonnes.

To assess the GHG emission impacts from the project, the analyst must calculate the **change in annual energy consumption** resulting from the upgrade project, and then apply the appropriate emissions factor.

Project Boundaries: The project will involve the refining stage of the fuel cycle.



Assumptions:	Fuel	Value	Handbook Reference (Exhibit)
Net Calorific Value (TJ/ 10^3 tonnes)	Petroleum Coke	40.19	3-3
	Crude Oil	42.91	3-4
Carbon Emission Factor (t C/TJ)	Petroleum Coke	27.5	3-6
Fraction of Carbon Oxidized	Petroleum Coke	0.99	3-7

GHG Emissions Associated with the Refinery Project

Step 1: Define Project Boundaries

Because the project is not intended to catalyze specific shifts in the fuel mix of Chile or other countries that are refinery customers, the analysis does not assess the GHG emissions impacts of downstream effects on fuel use. Therefore, only the GHG impacts related to refining itself have been calculated.

Step 2: Estimate Annual Fuel Consumption Impact

To calculate the net annual change in fuel consumption at the refinery, the first step is to compute the amount of energy presently used. This requires that the annual feedstock first be converted into terajoules and the resulting figure then be multiplied by two percent, which represents the energy needed in the existing distilling operation. This value is then multiplied by ten percent to compute the increase in energy use as a result of the project.

Case Study 3-1 cont.

To convert to terajoules, one must multiply the annual feedstock of crude oil by the NCV for crude:

Oil processed Annually 5 million tonnes/yr	x	**Net Calorific Value NCV) for Crude Oil** 42.91 TJ/ 10^3 t	=	**Oil Processed Annually** TJ/yr

= 214,550 TJ

To compute energy use at the existing plant:

Oil processed Annually 214,550 TJ/yr	x	**Percentage of Embedded Energy Used in Distilling** 2 percent	=	**Annual Energy Use at Existing Plant** TJ/yr

= 4,291 TJ

Finally, to calculate the increase in energy use due to the refinery upgrade:

Annual Energy Use at Existing Plant TJ/yr	x	**Increase in Energy Use Due to Upgrade** 10 percent	=	**Change in Annual Energy Use** TJ/yr

= 429 TJ

The project increases refinery energy consumption by 429 TJ per year.

Step 3: Estimate Carbon Emissions Impact

The annual energy consumption impact is converted to an estimate of carbon emissions impact by multiplying by the carbon emission factor for petroleum coke.

Change in Annual Energy Use 429 TJ/yr	x	**Carbon Emission Factor for Petroleum Coke** 27.5 t C/TJ	=	**Carbon Emission Impact** t C/yr

= 11,800 tonnes

Step 4: Estimate Carbon Oxidized During Combustion

Correct for incomplete combustion by multiplying total carbon emissions by the fraction of carbon oxidized.

Carbon Emissions **11,800** t C/yr	x	**Fraction of Carbon Oxidized 99 %**	=	**Adjusted Annual Carbon Emissions** t C/yr

= 11,682 t C per year

Step 5: Estimate Carbon Dioxide Emissions

Convert to CO_2 emissions by multiplying corrected carbon emissions by 44/12.

Case Study 3-1 cont.

Adjusted Carbon Emissions	x	CO_2/C Conversion Factor	=	Annual Carbon Dioxide Emissions
11,682 t C		44/12 t CO_2/t C		t CO_2

= 42,835 tonnes of CO_2 per year

This is the total annual emissions impact of the petroleum refinery upgrade project. Over the life of the project (assumed to be 25 years), **emissions will total 1,070,873 tonnes of CO_2**. It should be noted, that the upgrade may also result in the substitution of lighter, cleaner-burning oil products for some of the heavier residual fuel oil now being used. However, this is not a direct impact of the refinery upgrade project and is therefore not included in the analysis.

3.6.2 Guidelines for Energy Conversion and Distribution Projects

Energy conversion projects involve the conversion of energy fuels to useful forms of energy. Examples include the combustion of biomass or fossil fuel to provide heat, steam or shaft power, or the conversion of shaft power to electricity. Transmission and distribution projects involve the transfer of useful energy to end users. Examples include the development of a natural gas pipeline to supply gas to a nearby city or large industrial customer, or the installation of an electricity transmission line.

Many World Bank projects will involve both the energy conversion and distribution stages of the energy cycle. Hence, a project analyst may need to consider multiple impacts when evaluating the GHG effects of a project. In addition, for more complex conversion projects the analyst may need to account for the project's impacts on GHG emissions from a variety of technology options and fuel types. For example, a project to construct a power plant may result in a reduction in electricity generation at several power facilities burning different fuels.

The major GHG impacts of energy conversion and distribution projects will normally relate to changes in energy consumption. It must also be noted, however, that these projects may also result in fugitive methane emissions (as in the case of natural gas pipeline projects) and in emissions resulting from land-use changes. For example, a T&D project may require land clearing that produces carbon dioxide emissions, and a large hydropower project may cause flooding that results in methane emissions from the decomposition of organic matter.

This chapter offers more specific guidance in two areas. First, it provides information on the assessment of the GHG impacts of **electricity generation, transmission and distribution projects, distinguishing between grid** (central, distributed, and mini-grid) and **off-grid** (stand-alone) systems. Second, it discusses **cogeneration projects**. Case studies are provided to illustrate the GHG impacts of transmission and distribution upgrade, and cogeneration projects.

GHG Impacts of Electric Grid Projects

Assessment of grid-electric project GHG emissions may be complicated because a project may affect the level of electricity generation at a number of power plants, each burning different fuels (and some using more than one fuel.) This section provides estimation techniques applicable to:

- central utility grids;
- mini-grids; and,
- distributed grid systems.

Whether the analyst is determining the net GHG impacts of additions (expansion or connection of mini-grids), improvements (repowering, upgrades), or construction projects, he or she must identify the technology and fuel changes occurring over the economic life of the electricity system and then account for the GHG impacts from these changes. Unlike off-grid systems, electric grid systems typically include **multiple fuel systems**. If this is the case, the total net annual projected GHG impact of a proposed project will be the sum of the changes at the individual plants. This means that the analyst, in following the GHG assessment steps outlined earlier, must sum across all technologies using the following formula:

Formula 3.11 Estimation of Total Annual GHG Emissions of Electric Grid Project

$$\Sigma_{f,s}\ (FC_{f,s} \times C \times O \times 44/12) = \text{Annual } CO_2 \text{ Emissions}$$

tonnes/yr tonnes/yr

where: f equals fuel type, s represents the technology employed, FC is annual consumption of a particular fuel type; and C and O are the carbon emission factor and combustion efficiency for that fuel, respectively.

In some cases technical consultants might provide the analyst with emissions factors per unit of output (kWh) rather than per unit of fuel input. In these cases the analyst should substitute kWh for FC in the above formula. Emissions factors may also have the oxidation factor and the CO_2/C conversion factor embedded in them. In these cases, Formula 3.10 may be simplified as follows:

$$\Sigma_{f,s}\ (FC_{f,s} \times EF_{f,s}) = \text{Annual } CO_2 \text{ Emissions}$$

t/yr t/yr

where: f equals fuel type, s represents the technology employed, FC is annual consumption of a particular fuel type; and EF is the carbon dioxide emission factor.

To calculate the **net project life GHG emissions** one simply adds up total annual net emissions:

Formula 3.12 Estimation of Total Net Project-Life GHG Emissions of Electric Grid Project

$$\Sigma_n\ (\text{Total Annual Net } CO_2 \text{ Emissions}) = \text{Total Net Project Life } CO_2 \text{ Emissions}$$

tonnes/yr tonnes

where n = years 1 to n

In practice, a first-order estimation of GHG impacts may be made for energy power projects by using the above methodology, but for more detailed assessment, other models need to be used. For example, introducing renewable energy system(s) into a grid may displace a specific combination of generation facilities or particular high-cost units that will be run less or taken off-line as a result of the availability of the renewable-based generation system. A rigorous assessment would require that one use a utility generation dispatch model (i.e., WASP, LOGOS, Pro-Mod, IRP etc.) to determine net GHG emission changes. The World Bank's *The Environmental Manual for Power Development* (World Bank 1996b) is a user-friendly computer model available on the Internet that permits analysts to evaluate the GHG and other air emissions impacts of electricity generation projects that affect the dispatch of complex grid systems. For large power projects, this model may be the best standardized tool for estimating GHG impacts.

Case Study 3.2 provides a closer look at the calculation of the GHG impacts of a T&D upgrade project.

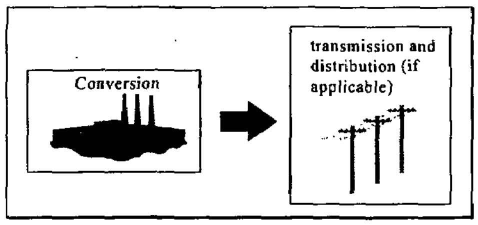
Case Study 3-2: Transmission and Distribution System Upgrade[3]

Project Summary

Project Type:	Transmission and Distribution System Improvement
Energy Cycle Stage Involved:	Coal Conversion, Transmission and Distribution, Conversion
Fuel Used:	Anthracite Coal
Project Economic Life:	25 years
Net GHG Impact (CO_2-equivalent tonnes):	Reduction in annual GHG emissions are expected to equal 81,062 tonnes; emissions reductions over the life of the project will be over two million tonnes.

Introduction: This project in India involves a transmission and distribution (T&D) system upgrade that will eliminate technical losses suffered in delivering power to end users. The grid will be redesigned to raise power factors and improve sub-station and transformer efficiencies and balance loads. The improvements will reduce losses from 20 percent of power input to ten percent. The upgrade will not address "non-technical" losses. The power plant has a rated capacity of 100 MW and burns anthracite coal. It converts 33 percent of its fuel requirement into delivered electricity and provides the local city with 2,000 TJ of electricity each year.

To calculate the total greenhouse gas emissions impact from this project, the analyst must estimate the change in the energy requirement of the power plant due to the upgrade and apply the correct carbon emissions factor.



Project Boundaries: The project will involve the conversion and transmission and distribution stages of the energy cycle.

Assumptions:	Fuel	Value	Handbook Reference (Exhibit)
Carbon Emission Factor (t C/TJ)	Anthracite Coal	26.8	3-6
Fraction of Carbon Oxidized	Anthracite Coal	0.98	3-7

GHG Impact Calculation

Step 1: Define Project Boundaries

The purpose of this T&D upgrade project will be to reduce the amount of energy needed to provide electricity to end users, rather than to improve T&D for its own sake. The boundary of the greenhouse gas emissions analysis therefore is drawn to include both the power plant and the grid. The end users are not included because their energy use is assumed constant.

Step 2: Estimate Fuel Consumption Impact

Annual delivered electricity is a function of power plant net conversion efficiency and T&D losses. These relationships are described in the following two equations:

Case Study 3-2 cont.

T&D Upgrade Case Study Formula 1:

Annual Power Plant Fuel Requirement TJ/yr	x	**Plant Net Conversion Efficiency Factor** %	=	**Annual Power Produced (net of on-site use)** %

and

T&D Upgrade Case Study Formula 2:

Annual Net Power Produced TJ/yr	x	**(1 - T&D Losses)** %	=	**Annual Power Delivered** TJ/yr

The second equation may be arranged as follows:

Annual Power Delivered TJ/yr	/	**(1 - T&D Losses)** %	=	**Annual Net Power Produced** TJ/yr

By applying this formula the analyst may compute the change in annual net power produced due to the T&D system upgrade:

Annual net power produced before the project:

Annual Power Delivered 2,000 TJ/yr	/	**(1 - T&D Losses)** 80 %	=	**Annual Net Power Produced** TJ/yr

= 2,500 TJ/yr

Annual net power produced after the upgrade:

Annual Power Delivered 2,000 TJ/yr	/	**(1 - T&D Losses)** 90 %	=	**Annual Net Power Produced** TJ/yr

= 2,222 TJ/yr

The change in net power produced as a result of the upgrade is therefore 2,500 - 2,222 = **278 TJ per year**. By rearranging and then applying Formula 1 of this case study, this number may be converted into an estimate of the change in the plant's fuel requirement:

Change in Annual Net Power Produced 278 TJ/yr	/	**Plant Net Conversion Efficiency Factor** 33 %	=	**Annual Power Plant Fuel Requirement** TJ/yr

= 842 TJ/yr

Step 3: Estimate Carbon Emissions Impact

The annual energy consumption impact is converted to an estimate of carbon emissions impact by multiplying by the carbon emission factor for anthracite coal.

Change in Annual Energy Use 842 TJ/yr	x	**Carbon Emission Factor for Anthracite** 26.8 t C/TJ	=	**Carbon Emission Impact** t C/yr

= 22,559 tonnes

Case Study 3-2 cont.

Step 4: Adjust for Carbon Not Oxidized During Combustion

Correct for incomplete combustion by multiplying total carbon emissions by the fraction of carbon oxidized.

Carbon Emissions	x	Fraction of Carbon Oxidized	=	Adjusted Annual Carbon Emissions
22,559				
t C/yr		98 %		t C/yr

= 22,108 t C per year

Step 5: Estimate Carbon Dioxide Emissions Impact

Convert to CO_2 emissions by multiplying corrected carbon emissions by 44/12.

Adjusted Carbon Emissions	x	CO_2/C Conversion Factor	=	Annual Carbon Dioxide Emissions
22,108 t(C)		44/12		
		t CO_2/t C		t CO_2

= 81,062 tonnes of CO_2 per year

By reducing the power plant fuel requirement, the T&D upgrade project reduces carbon dioxide emissions by **81,062 tonnes** each year. Over the economic life of the project, CO_2 emissions reductions will total **2,026,543 tonnes**.

GHG Impacts of Off-Grid Projects

Off-grid systems are also known as **stand-alone projects**. These systems may include:

- **remote power systems** (e.g., power systems dedicated to a single community or cluster of communities and separate from the power grid); and
- **captive power systems** (e.g., power systems dedicated to industrial processing, mining plants, and other institutional applications).

The stand-alone characteristic of off-grid electric projects reduces the complication of analyzing the GHG emissions.

In the case of **rural electrification systems**, which may or may not involve grids, the calculation of total net GHG impacts follows the same set of basic equations outlined above for electric grid systems (Formulas 3.11 and 3.12). The distinction for World Bank projects is that as changes in the mix of rural energy delivery systems and technologies are introduced, each energy service (e.g. climate control, lighting, electrification) must be assessed for its net GHG impacts.

Formula 3.13 Estimation of Total Annual GHG Emissions of Off-Grid Project				
$\Sigma_{f,s}$ ($FC_{f,s}$ TJ/yr	x	$EF_{f,s}$) tonnes CO_2-equiv/TJ	=	**Total Annual Energy Service GHG Emissions** tonnes/yr

where:

f = fuel type, s = technology employed, FC = is consumption of a particular fuel type; and EF = carbon dioxide emission factor (adjusted for fuel combustion efficiency) for that fuel, respectively.

For a comparative analysis, total annual emissions for both scenarios being compared would be summed over the project life (years 1 to n) to derive the **total life-cycle GHG emissions from the energy service mix.** The final step is to complete the comparative analysis by deriving the total **net GHG emissions** for the reference and project scenarios. First-cut analyses can be readily made through these equations, and, if desired, the *Environmental Manual* (World Bank 1996b) may be used to conduct more detailed assessments.

GHG Impacts of Cogeneration Projects

A cogeneration, or combined heat and power (CHP) system produces heat that is used both to generate electrical power and steam (or another hot gas) for industrial processing and district heating and cooling. The combination of highly efficient energy usage in the form of electrical power and steam can result in system thermal efficiencies of 80 percent and higher, compared to efficiencies of 30 to 40 percent at most power plants. The success of a cogeneration plant is dependent upon the efficiency of the system hardware and the ability of the plant operators to optimize the thermodynamic cycle. Included in the conversion of a conventional power plant to a cogeneration plant is the addition of new hardware as well as the upgrade of certain existing hardware to reach the efficiency requirements of a cogeneration cycle.

The conversion of a conventional power generation system to a cogeneration system allows for the utilization of heat energy that would otherwise be rejected to the atmosphere. Increased thermal efficiency may result in reduced plant fuel consumption and therefore lower greenhouse gas emissions. Alternately, the facility may produce more useful energy than it requires, allowing it to sell surplus energy. This activity may displace the use of a higher carbon fuel, thereby mitigating GHG emissions. Case Study 3.3 demonstrates the methodology for assessing the GHG impacts of cogeneration projects.

3.6.3 GHG Impacts of Transportation Projects

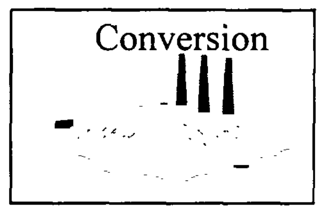
As noted, the methodology presented in this chapter may be applied to account for the energy-related impacts of industry sector and infrastructure projects. One type of infrastructure project that merits further discussion is transportation, because transport-related fuel use is a major contributor to global GHG production.

Many World Bank projects involve the major transport activities, which are rail, road, air and ship transport. These activities may produce significant emissions of greenhouse gases, including carbon dioxide, methane, nitrous oxide, carbon monoxide, nitrogen oxides, and non-methane volatile organic compounds. Emission impacts are primarily a function of changes in fuel consumption caused by the project; in addition, land clearing related to transport projects may result in carbon dioxide emissions.

Case Study 3-3: Bagasse Cogeneration Project[4]

Project Summary	
Project Type:	Power plant upgrade to bagasse cogeneration; displacement of coal-fired electricity generation
Energy Cycle Stage Involved:	Energy conversion
Project Economic Life:	15 years
Net GHG Impact (CO_2):	Carbon dioxide emissions reductions of 36,770 tonnes per year, or 551,544 tonnes over the life of the project

Introduction: The proposed project will involve the improvement of a bagasse-fueled power plant located at a sugar mill. The plant burns the bagasse remaining from sugar processing, generating all of the power needed in the fully electricity-driven sugar mill. The plant upgrade will convert the power plant to a cogeneration facility producing steam to be used for both sugar processing and to generate electricity. The new facility will accommodate all sugar mill steam and power requirements and will produce 35 million kilowatt-hours (kWh) of surplus power for sale to the grid during the sugar season. This electricity will displace the use of power generated from anthracite coal. It is assumed that the percentage losses associated with the transmission and distribution of electricity from the bagasse-fired and coal-fired facilities are equal.



System Boundaries: The project will involve the energy conversion stage of the energy cycle and is drawn to include the coal-fired power plant.

Assumptions:	Fuel	Value	Handbook Reference (Exhibit)
Carbon Emission Factor (t C/TJ)	Anthracite	26.8	3-6
Fraction of Carbon Oxidized	Anthracite	0.98	3-7

GHG Impact Calculation

Step 1: Define project boundaries

The purpose of converting the power plant to a cogeneration facility is to produce and sell electricity using surplus bagasse. The project therefore involves only the energy conversion stage of the fuel cycle.

Step 2: Estimate Fuel Consumption Impacts

The bagasse cogeneration plant will both improve the energy efficiency of the existing sugar mill and generate excess power for export. The fuel requirement of the facility prior to and after the conversion to cogeneration are the same, as both the old and new systems use the same amount of bagasse. The only change in fuel use that will have a greenhouse gas impact is the displacement of electricity produced from coal by the surplus power generated by the project. This is because bagasse combustion results in no carbon dioxide emissions, while coal burning does have a CO_2 impact. (CO_2 emissions resulting from bagasse combustion are zero because the release of CO_2 upon burning is assumed to be exactly offset by the capture of carbon dioxide by growing the sugar cane.) It is therefore necessary to calculate the amount of energy (TJ) embodied in the coal that is displaced. Using Formula 3.1, this amount is estimated as follows:

Case Study 3-3 cont.

Plant Electricity Output	x	Conversion Factor	/	Coal Plant Conversion Efficiency	x	Conversion Factor	=	Coal Plant Fuel Requirement Displaced
35×10^6 kWh/yr		3.6×10^6 J/kWh		Assume 33%		1 TJ/10^{12} J		TJ/yr

= 382 TJ/yr

Step 3: Estimate Carbon Emissions Impact

To calculate annual carbon from the burning of coal, multiply the annual energy produced by the carbon emission factor for coal.

Annual Energy Produced	x	Carbon Emission Factor	=	Annual Carbon Impact
382 TJ/yr		26.8 t C/TJ		t C/yr

= 10,233 tonnes (C) per year

Step 4: Adjust for Carbon Not Oxidized During Combustion

Correct for incomplete combustion by multiplying total carbon emissions by the fraction of carbon oxidized.

Carbon Emissions	x	Fraction of Carbon Oxidized	=	Adjusted Annual Carbon Emissions
10,233 t C/yr		98 %		t C/yr

= 10,028 t C per year

Step 5: Estimate Carbon Dioxide Emissions Impact

Convert to CO_2 emissions by multiplying corrected carbon emissions by 44/12.

Adjusted Carbon Emissions	x	CO_2/C Conversion Factor	=	Annual Carbon Dioxide Emissions
10,028 t C		**44/12** t CO_2/t C		t CO_2

= 36,770 tonnes of CO_2 per year

Over the course of the project, the bagasse cogeneration project will result in a reduction in carbon dioxide emissions from coal-fired generation of **36,770** each year. Assuming a project economic life of 15 years, the total project avoided emissions will be **551,544** tonnes of CO_2.

Energy-related GHG Impacts of Transport Sector Projects

The major source of GHG emissions from transport sector projects is fuel consumption by "mobile sources" (automobiles, trains, ships, etc.) Road transport typically accounts for the majority of mobile source fuel consumption in developing countries, followed by water and air transport (UNEP/OECD/IEA/IPCC 1995).

The major fuel types involved in transport projects include gasoline, diesel, jet kerosene, aviation gasoline, natural gas, liquefied petroleum gas and residual fuel oil. The level of carbon dioxide emissions is determined primarily by fuel carbon content and combustion efficiency. CH_4 emissions are a function of the methane content of the fuel, combustion efficiency and any post-combustion control of hydrocarbon emissions, such as the use of catalytic converters. In uncontrolled engines, emissions of CH_4 generally are highest at low speeds, when the engine is idling and in poorly-tuned engines. N_2O emissions from vehicles are thought to be small relative to total anthropogenic emissions and need not be considered by project analysts. N_2O emission rates are, however, substantially higher when certain emission control technologies (especially catalysts on road vehicles) are used (UNEP/OECD/IEA/IPCC 1995).

To calculate the energy-related GHG impacts of transport projects, the analyst may follow the steps for assessing energy sector project impacts described in section 3.3. In applying the energy sector methodology, the analyst is likely to find the most difficult step to be the estimation of transport projects fuel consumption impacts. The major factors that influence fuel consumption levels include:

- transport class (e.g., rail, road, ships, air);
- fuel consumed (e.g., diesel, gasoline);
- operating characteristics (e.g., system efficiencies);
- emission controls;
- maintenance procedures; and,
- system (fleet) age and turnover.

The basic information required by a World Bank analyst therefore includes types of fuels consumed as a result of the project; combustion technologies used; operating conditions during combustion; and the extent of emission control technologies employed. Ideally, the analyst will be able to estimate carbon emissions from consumption of each fuel type, broken down by vehicle type and emission control technology. The analyst can then sum the carbon emissions for each category. To do this he or she may use the equation provided earlier for electric grid projects (Formula 3.11). Emissions over the life of the project may then be computed using Formula 3.12.

Land-Use GHG Impacts of Transport Sector Projects

The construction of transportation systems often involves significant land clearing, which may result in the release of substantial amounts of carbon dioxide to the atmosphere. The methodology for assessing this impact is provided in Chapter 5.

3.6.4 GHG Impacts of Energy Efficiency Projects

This section provides an overview of the methods used to assess the GHG impacts of energy efficiency projects. Many projects undertaken by the World Bank involve activities that introduce more efficient technological systems that use less energy to produce the same product or service as a competing option. These systems may be used at any stage of the energy cycle. Examples include a project to improve coal mining efficiency (extraction stage); a project to improve the technological processes at a sugar mill (conversion stage); and a "demand side management" project to diffuse more efficient lighting equipment to residential electricity users (end use stage).

The World Bank supports both energy efficiency and energy conservation projects.

- **Energy efficiency projects** focus on modifications in technological systems to use less energy. Examples include improvements in lighting, climate control, and motors.
- **Energy conservation projects** focus on changing energy consumption use patterns. These types of projects generally include changing behavior and technical use. For

example, during peak periods, utilities often must rely on oil- or coal-fired power plants to provide electricity. If major industries reduce or eliminate energy intensive processes during morning and evening peak periods, they can reduce the need to add costly and GHG emitting capacity.

In practice, many World Bank energy projects involve a combination of energy efficiency and conservation measures that typically result in low- and no-cost options for various consumer groups - industries, commercial buildings, and households.

Assessment Procedures for Energy Efficiency Projects

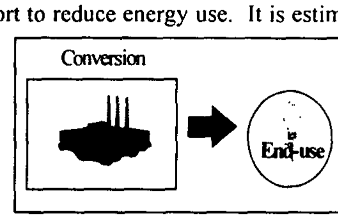
The emission assessment process for energy efficiency projects is the same as that for all energy projects, as outlined in section 3.3. The only unique element in analyzing energy efficiency projects is that in some demand side cases there may be a large number of project participants. For example, a residential sector project may involve 10,000 or more households. Statistical tools may be needed to derive a representative sample of the overall population participating in the project, because cost and time restraints typically restrict the analyst from performing an analysis on the entire population. Annex 7 gives the methodology for developing a statistical sample.

Case Study 3-4: Residential and Commercial Sector DSM Project[5]

Project Summary	
Project Type:	Asian Efficient Lighting Project
Energy Cycle Stage Involved:	Energy End Use
Fuel Used:	Various
Project Economic Life:	5 years
Net GHG Impact (CO_2-equivalent tonnes):	The project will reduce CO_2 emissions by nearly 8,000 tonnes per year, or nearly 40,000 tonnes over the life of the project.

Introduction: A lighting project in Asia is attempting to reduce the lighting load in commercial buildings to save energy and reduce associated GHG emissions. The buildings are located in two Asian countries, and include large and small office buildings as well as retail stores. The project's technical goal is to replace the standard 3-lamp, fixed ballast fixture with a 2-lamp, high-efficiency fluorescent fixture in an effort to reduce energy use. It is estimated that energy consumption will be decreased by 100 TJ per year as a result of the project.

Project Boundaries: The project will involve both the conversion and end use stages of the fuel cycle.



Assumptions:	Fuel	Value	Handbook Reference (Exhibit)
Carbon Emission Factor (t C/TJ)	Various	22	Given
Fraction of Carbon Oxidized	Various	0.99	Given

Case Study 3-4 cont.

GHG Impact Calculation

Step 1: Define Project Boundaries

The purpose of this project will be to reduce the amount of energy needed to provide lighting to end users. The boundary of the analysis therefore is drawn to include both the power plant and end use.

Step 2: Estimate Fuel Consumption Impact

The energy consumption of the project has been estimated to be ten TJ per year.

Step 3: Estimate Carbon Emissions Impact

Technical experts consulting for the project determined that the carbon emissions factor for the generating facilities that will be displaced by the project is 22 t C/TJ. Therefore,

Change in Annual Energy Use	x	**Carbon Emission Factor Country A, B**	=	**Carbon Emission Impact**
100 TJ/yr		22 t C/TJ		t C/yr

= 2,200 tonnes

Step 4: Adjust for Carbon Not Oxidized During Combustion

Correct for incomplete combustion by multiplying total carbon emissions by the fraction of carbon oxidized. The consultants to the project determined this factor to be 99 percent.

Carbon Emissions 2,200	x	**Fraction of Carbon Oxidized** 99 %	=	**Adjusted Annual Carbon Emissions**
t C/yr				t C/yr

= 2,178 t C per year

Step 5: Estimate Carbon Dioxide Emissions Impact

Convert to CO_2 emissions by multiplying corrected carbon emissions by 44/12.

Adjusted Carbon Emissions	x	**CO_2/C Conversion Factor 44/12**	=	**Annual Carbon Dioxide Emissions**
2,178 t C		t CO_2/t C		t CO_2

= 7,986 tonnes of CO_2 per year

By reducing the power plant fuel requirement, the T&D upgrade project reduces carbon dioxide emissions by **7,986 tonnes** each year. Over the economic life of the project, CO_2 emissions reductions will total **39,930 tonnes**.

3.7 Summary

This chapter has provided simple methodologies to estimate the GHG impacts of energy projects. The chapter presents the equations needed to assess:

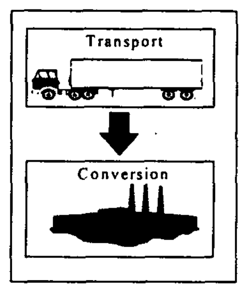
- the carbon dioxide emissions impacts associated with fuel combustion;
- fugitive methane emissions associated with energy extraction, processing and transportation; and
- nitrous oxide and methane emissions resulting from biomass combustion.

This chapter has emphasized the fact that many World Bank energy sector projects will have multiple GHG impacts. Therefore, in assessing project GHG impacts it is important that the analyst consider all major effects. Case Study 3.5 presents a comprehensive project GHG impact assessment of a natural gas pipeline development project. This case study includes an assessment of both energy-related CO_2 emissions and fugitive methane emissions impacts, and it provides a comparative analysis of the proposed pipeline project to a reference scenario.

Case Study 3-5: Natural Gas Pipeline Construction[6]

	Project Summary
Project Type:	Pipeline construction, fuel substitution
Energy Cycle Stage Involved:	Energy transport, conversion
Fuels Involved:	Substitution of natural gas for coal, diesel and kerosene.
Project Economic Life:	30 years
Net GHG Impact (CO_2-equivalent tonnes):	A reduction of 80,000 tonnes per year; or 2.4 million tonnes over the life of the project.

Introduction: A proposed project will involve the construction of a pipeline to carry 125 million cubic meters per year of natural gas to Novonansk, a mid-size city in Russia. Forty percent of the gas will displace sub-bituminous coal and 40 percent will displace diesel at local power plants, while 20 percent will displace kerosene used in residences. The analysis presented here includes an assessment of the emissions of both the natural gas project and the fuels it will displace. It therefore reveals the net GHG impact of the project.



Project Boundaries: The project will involve the energy transport and conversion stages of the fuel cycle.

Assumptions:	Fuel	Value	Handbook Reference (Exhibit)
Density (tonnes/10^3 m^3)	Natural Gas	0.67	Text
Energy Content (TJ/ 10^3 tonnes)	Natural Gas	51.55	Text
Carbon Emission Factor (t C/TJ)	Natural Gas	14.5	3-6
	Coal	26.2	3-6
	Diesel	20.2	3-6
	Kerosene	19.6	3-6
Fraction of Carbon Oxidized	Natural Gas	0.995	3-7
	Coal	0.98	3-7
	Diesel	0.99	3-7
	Kerosene	0.99	3-7

Case Study 3-5 cont.

GHG Impact Calculation

GHG Emissions Associated with the Pipeline Project

A. GHG Emissions from Fuel Combustion

Step 1: Define project boundaries

Because the purpose of this project is to feed natural gas to particular energy users in Novonansk rather than simply make natural gas available in the local market, the boundary for this project is drawn to include the pipeline and Novonansk. The major direct gross GHG impacts of the project, therefore, will result from the combustion of natural gas. These impacts must be offset by those from the burning of coal, oil and kerosene. In addition, methane emissions from the pipeline must be taken into consideration in the analysis.

Step 2: Estimate Fuel Consumption

The assumptions above state that the new pipeline will result in annual consumption of an additional 125 million m^3 of natural gas by Novonansk.

Step 3: Estimate Carbon Emissions Impact

It is first necessary to convert the annual volume of natural gas to units of energy (terajoules), so that a carbon emission factor may then be applied.

Consumption (volume)	x	NCV for natural gas	x	Conversion Factor	=	Fuel Consumption
125 million m^3/yr		3.454×10^7 J/m^3		10^{-12} TJ/J		TJ

= 4,318 TJ per year

This figure may then be converted to an estimate of carbon emissions impact by multiplying by the carbon emission factor for natural gas.

Fuel Consumption	x	Carbon Emission Factor	=	Gross Annual Carbon
4,318 TJ		14.5 t C/TJ		t C/yr

= 62,604 tonnes per year

Step 4: Estimate Carbon Oxidized During Combustion

Correct for incomplete combustion by multiplying total carbon emissions by the fraction of carbon oxidized.

Carbon Emissions	x	Fraction of Carbon Oxidized	=	Adjusted Annual Carbon Emissions
62,604 t C/yr		99.5 %		t C/yr

= 62,290 t(C) per year

Case Study 3-5 cont.

Step 5 Estimate Carbon Dioxide Emissions

Convert to CO_2 emissions by multiplying corrected carbon emissions by 44/12 (the molecular ratio of CO_2 to C.)

Adjusted Carbon Emissions	x	**CO_2/C Conversion Factor**	=	**Annual Carbon Dioxide Emissions**
62,290 t C		44/12 t CO_2/t C		t CO_2

=228,399 tonnes of CO_2 per year

B. Pipeline System Methane Leakages

Assume that World Bank consultants have estimated methane leakages associated with the new gas system to be 400,000 kg/PJ of energy consumed.

Step 1: Estimate Fugitive Methane Emissions

This leakage rate given above, which is consistent with pipeline leakage estimates include in the *IPCC GHG Inventory Guidelines* (IPCC 1995), translates into 0.4 tonnes of methane per terajoule. This figure may then be multiplied by annual terajoule use to estimate annual methane fugitive emissions:

Annual Fuel Consumption	x	**Methane Leakage Rate**	=	**Annual Methane Emissions**
4,318 TJ		0.4 t CH_4/TJ		t CH_4

= 1,727 tonnes of methane per year

Step 2: Convert to units of carbon dioxide-equivalent emissions

This is done by multiplying the figure from Step 1 by the global warming potential of methane, which is 24.5.

Project Fugitive Methane Emissions	x	**GWP of Methane**	=	**Project Fugitive Methane Emissions**
1,727 t CH_4		24.5 t CO_2-equivalent/t CH_4		t CO_2-equivalent

= 42,312 tonnes of CO_2-equivalent emissions per year

This figure represents about 19 percent of emissions associated with natural gas combustion.

C. Total Project GHG Emissions

Annual project GHG impacts total 228,399 + 42,312 = **270,711 tonnes of carbon dioxide-equivalent emissions.**

Assuming a project economic life of 30 years, total project emissions will be **8,121,325 tonnes.**

GHG Emissions Associated with the Old Energy System: Reference Case

Emissions from the pipeline project may then be compared to those from the existing system in order to compute the net impact of the project.

Case Study 3-5 cont.

A. GHG Emissions from Fuel Combustion

Step 1: Define project boundaries

Current fuel sources used in Novonansk include coal, diesel and kerosene.

Step 2: Estimate Annual Fuel Consumption

We know that the total fuel requirement for Novonansk now equals 4,318 TJ per year. Because the fuel mix is 40 percent coal, 40 percent diesel and 20 percent kerosene, annual consumption of these fuels is 1,727 TJ each of coal and diesel and 864 TJ of kerosene.

Step 3: Estimate Carbon Emissions Impact

For each of the fuels, consumption figures are multiplied by carbon emission coefficients to estimate annual carbon dioxide impacts.

Fuel	Fuel Use TJ x	Carbon Emission Factor t C/TJ =	Carbon Emissions t C
Coal	1,727	26.2	45,247
Diesel	1,727	20.2	34,885
Kerosene	864	19.6	16,925
Total			**97,057**

Total unadjusted carbon emissions equals **97,057 tonnes per year**.

Step 4: Estimate Carbon Oxidized During Combustion

Correct for incomplete combustion by multiplying total carbon emissions by the fraction of carbon oxidized.

Fuel	Carbon Emissions t C x	Fraction of Carbon Oxidized (%) =	Adjusted Carbon Emissions t C
Coal	45,247	0.98	44,342
Diesel	34,885	0.99	34,537
Kerosene	16,925	0.99	16,755
Total	**97,057**		**95,634**

Total adjusted annual carbon emissions equal **95,634 tonnes**.

Step 5: Estimate Annual Carbon Dioxide Emissions

Convert to CO_2 emissions by multiplying corrected carbon emissions by 44/12 (the molecular ratio of CO_2 to C).

Annual Carbon Emissions	x	**CO_2/C Conversion Factor**	=	**Annual Carbon Dioxide Emissions**
95,634 t C		44/12 t CO_2/t C		t CO_2

= **350,659 tonnes of CO_2 per year**

Case Study 3-5 cont.

B. Coal and Oil System Methane Leakages

World Bank consultants have estimated fugitive methane emissions associated with the transport and distribution of coal, diesel and kerosene to be very small. These emissions therefore may be ignored in the assessment of existing system GHG emissions.

C. Total Reference Case GHG Emissions

Total annual GHG impacts associated with existing fuel processing and conversion for Novonansk equal **350,659 tonnes of carbon dioxide (or carbon dioxide-equivalent.)**

Again assuming a project economic life of 30 years, total emissions will be **10,519,779 tonnes**.

Comparative GHG Project Analysis: Net GHG Impacts

The GHG impacts of the existing and proposed systems may now be compared:

	(1) Coal/Diesel/ Kerosene System	(2) Natural Gas System	Difference
Annual GHG Impacts (t/yr)	350,659	270,711	**79,948**
Lifetime GHG Impacts (t)	10,519,779	8,121,325	**2,398,453**

The above table shows that the natural gas pipeline project will result in a reduction of nearly **80,000 tonnes of carbon dioxide emissions per year**, and a reduction of almost **2.4 million tonnes over the life of the project**. The project will thus provide a **23 percent** reduction in GHG emissions relative to the existing coal/diesel/kerosene fuel mix.

Endnotes

[1] The atomic weights of carbon and oxygen are 12 and 16, respectively. The molecular weight of CO_2 thus equals 12 + (2 x 16) = 44.

[2] The project described here is fictitious and is presented for illustrative purposes only. It is not intended to resemble any actual or proposed project.

[3] The project option described here is fictitious and is presented for illustrative purposes only. It is not intended to resemble any actual or proposed project.

[4] The project option described here is fictitious and is presented for illustrative purposes only. It is not intended to resemble any actial or proposed project.

[5] The project described here is fictitious and is presented for illustrative purposes only. It is not intended to resemble any actual or proposed project.

[6] The project option described here is fictitious and is presented for illustrative purposes only. It is not intended to resemble any actual or proposed project.

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Industry and Infrastructure Project Methodology

4.1 Introduction

This chapter addresses the GHG impacts of industry and infrastructure projects that involve non-energy-related activities that produce greenhouse gas emissions. These include:

- Cement manufacture, which involves chemical processes that result in carbon dioxide emissions;
- Fertilizer production, which as a result of the use of nitric acid as a feedstock leads to nitrous oxide emissions; and
- The accumulation of waste in landfills. The decomposition of organic matter in these landfills produces methane.

Because the net CO_2 emissions from biomass are assumed to be zero (in closed loop systems), industrial processes that produce CO_2 emissions based on biomass carbon inputs (e.g., beverages, food, etc.) are not considered in this chapter.

Exhibit 4.1
Non-Energy Industry and Infrastructure Sources of Greenhouse Gases

Greenhouse Gas	Major Industrial Sources
Carbon Dioxide (CO_2)	Cement production
Methane (CH_4)	Landfill operation
Nitrous Oxide (N_2O)	Fertilizer production Adipic acid production

Many World Bank industry and infrastructure projects will have GHG emissions impacts that result from changes in energy consumption. To assess the impacts of energy-related industry and infrastructure activities, the analyst should apply the methodology presented in Chapter 3 for energy projects. Also, many World Bank industry and infrastructure projects involve land clearing, which results in the release of carbon dioxide emissions. Land use project GHG impacts are addressed in Chapter 5.

4.2 GHG Assessment Methodology

4.2.1 Cement Manufacture

From a global perspective, cement manufacture is the most important non-energy source of CO_2 emissions from the industrial sector. CO_2 emissions from cement processing represent 2.4 percent of total global CO_2 emissions (UNEP/OECD/IEA/IPCC 1995) and approximately seven percent of total non-fuel based GHG emissions. Clinker production involves the dissociation of calcium carbonate under heat, resulting in lime and CO_2. The lime then combines with other materials to form clinker, while the CO_2 is released to the environment. Pulverized clinker mixed with gypsum is called "Portland cement", which is the dominant type of cement produced around the world.

Because all CO_2 from cement manufacture is emitted from clinker production, GHG emission estimates should be calculated on the basis of lime content and clinker production. If the details of clinker production are unknown, lime content in the cement may substitute.

Step 1: Calculate the Carbon Dioxide Emissions Factor

To calculate the carbon dioxide emissions factor for cement manufacture, multiply the lime fraction in the clinker or in the cement by the molecular weight ratio of CO_2 (44 g/mole) to CaO (56.08 g/mole). The default value for lime fraction in clinker is **64.5%** and the default factor for lime fraction in "Portland cement" is **63.5%.** If the details of clinker production are not available, it is possible to calculate the emissions factor from the overall cement production.

Formula 4.1 Estimate the Carbon Dioxide Emissions Factor for GHGs

Lime Content of Cement or Clinker	x	**CO_2 /CaO Conversion Factor (44/56.08)**	=	**CO_2 Emissions Factor**
% CaO		t CO_2 /t CaO		% CO_2

Step 2: Calculate Total Annual Carbon Dioxide Emissions

To calculate total annual emissions, multiply the emissions factor by the amount of clinker or cement produced, depending on which emissions factor is available.

Formula 4.2 Estimate Total Annual Carbon Dioxide Emissions from Cement Project

Annual Cement or Clinker Production	x	**Emissions Factor**	=	**Total Annual CO_2 Emissions**
t /yr		% CO_2		t CO_2/yr

4.2.2 Adipic Acid and Fertilizer Manufacturing

Adipic acid and fertilizer production are both responsible for the release of nitrous oxide into the atmosphere. The production of adipic acid for nylon manufacturing involves the oxidation of cyclohexane, an intermediate material, with nitric acid (HNO_3), resulting in the emission of nitrous oxide. The use of nitric acid as a feedstock in fertilizer production also results in N_2O emissions.

To calculate the GHG emissions impacts of adipic acid production, the analyst will multiply the amount of acid produced in the project by the N_2O emission factor. The default value for unabated adipic acid production emissions is **300 g N_2O/kg of adipic acid produced** (Thiemens and Trogler 1991, as cited in UNEP/OECD/IEA/IPCC 1995). To assess the impact of fertilizer production, multiply the amount of nitric acid used by the N_2O emission factor. The default range for nitric acid production emissions is 2-9 g N_2O/kg HNO_3 (Reimer et. al. 1992; McCulloch 1993). If abatement technologies are employed, subtract the appropriate percentage of emissions from the total. Values for conversion factors for these processes are provided for the analyst in Exhibit 4-2.

The methodology for estimating GHG emissions from these processes is:

Step 1: Estimate Annual Nitrous Oxide Emissions

Formula 4.3 Estimate Total Annual N_2O Emissions from the Process

Amount of Acid Produced	x	Emissions Factor	x	Conversion Factor	=	Annual N_2O Emissions
kg/yr		g N_2O /kg Acid		10^{-6} t/g		t/yr

Step 2: Convert to Annual Carbon Dioxide-equivalent Emissions

Convert to carbon dioxide-equivalent emissions by multiplying annual nitrous oxide emissions by the global warming potential for nitrous oxide, which is currently estimated to be 320.

Formula 4.4 Estimate Total Annual N_2O Emissions from the Process

Annual N_2O Emissions	x	Global Warming Potential for N_2O	=	Annual CO_2-equivalent Emissions
t/yr		320		t/yr

4.2.3 Solid Waste/Landfills

Gas is produced at landfills and open dumps by the anaerobic decomposition of organic matter. This landfill gas (LFG) migrates through waste and through the landfill's soil cover into the atmosphere. LFG normally is about 50 percent (by volume) methane and 50 percent carbon dioxide, both of which are greenhouse gases. Because the CO_2 emissions are assumed to be exactly offset by carbon sequestration, however, they are not counted as net greenhouse gas emissions to the atmosphere. Methane emissions from landfills, on the other hand, do contribute to the atmospheric buildup of GHGs.

Exhibit 4-2
Estimated Emission Factors And Abatement Factors For Industrial Sources Of N_20

Activity	Emission Factor ($g N_2O/kg$)	Emission Factor Range ($g N_2O$) /kg)	Percentage Abated (%)
Adipic acid production	300	-	32
Nitric acid production	NA	2-9	0*

* At present no specific N_2O abatement techniques are in use.

Source: (Olivier 1993b) and references therein (Thiemens and Trogler 199 1); (McCulloch 1993).

The methodology for estimating GHG emissions from these processes is provided below.

Step 1: Estimate Annual Methane Emissions from the Landfill

To estimate landfill methane emissions, multiply total annual landfill gas emissions by the methane content of the gas (given in percentage terms, by volume.) The recommended default factor for this parameter is **50 percent.**

Formula 4.5 Estimate Annual CH_4 Emissions from the Landfill				
Annual Landfill Gas Produced m^3/yr	x	**Methane Content of Landfill Gas** %	=	**Annual CH_4 Emissions** m^3/yr

It is important to remember that landfill gas may be captured and then used as an energy fuel. If a project includes a component for landfill gas capture, then the estimate of annual landfill gas emissions should be reduced accordingly.

Step 2: Convert from Volume to Mass

The annual volume of methane production must then be converted into tonnes. The default value for methane density is **670 g/m³**.

Formula 4.6 Convert Methane Volume to Mass						
Annual CH_4 Emissions m^3/yr	x	**Methane Density** 670 g/ m^3	x	**Conversion Factor** 10^{-6} t/g	=	**Annual CH_4 Emissions** t/yr

Step 3: Convert to Annual Carbon Dioxide-equivalent Emissions

Convert to carbon dioxide-equivalent emissions by multiplying annual methane emissions by the global warming potential for methane, which is currently estimated to be 24.5.

Formula 4.7 Apply the Global Warming Potential of Methane				
Annual CH_4 Emissions t/yr	x	**Global Warming Potential for CH_4** 21	=	**Annual CO_2-equivalent Emissions** t/yr

Industry Case Study 4-1: Cement Plant[1]

Project Summary	
Project Type:	Cement Plant
Project Economic Life:	30 years
Net GHG Impact (CO_2- equivalent tonnes):	97,550 tonnes of CO_2 emissions annually, 2,926,500 tonnes over the project life.

Introduction: A proposed project involves the construction and operation of a coal-fueled cement factory which produces 100,000 tonnes of "Portland cement" annually. The cement factory will consume 500 TJ of energy per year for cement production activities. The project therefore involves two GHG-producing activities: energy use and clinker production.

Assumptions:	Value	Handbook Reference (Exhibit)
Fraction of Lime (CaO) in Cement	.63	Text
Carbon Emission Factor, Coal (t C/TJ)	26.8	5-5
Fraction of Carbon Oxidized, Coal	0.98	5-6

GHG Impact Calculation

Emissions From Chemical Reaction

Step 1: Calculate the Carbon Dioxide Emissions Factor

To calculate emissions from the chemical reaction process, the analyst should apply the following equation for the cement emissions factor.

Lime Content of Cement or Clinker	x	CO_2 /CaO Conversion Factor (44/56.08)	=	CO_2 Emissions Factor
63% CaO		t CO_2 /t CaO		% CO_2

= 0.494 tonnes (CO_2)/tonnes cement

Step 2: Calculate Total Annual Carbon Dioxide Emissions

The analyst then multiplies the annual cement production by the calculated emission factor to calculate total CO_2 emissions from non-energy cement production process.

Annual Cement or Clinker Production	x	Emissions Factor	=	Total Annual CO_2 Emissions
100,000 t /yr		0.494 t (CO_2)/t cement		t CO_2/yr

= 49,400 tonnes (CO_2)

The annual emission from chemical reaction for this project is 49,400 tonnes of CO_2.

Case Study 4-1 cont.

Emissions From Energy Use

Annual energy use in the cement factory will also result in greenhouse gas emissions. To calculate these emissions, follow the methodology from chapter 5, presented below.

Step 1: Estimate Fuel Consumption

Annual energy used at the plant is given as 500 TJ.

Step 2. Estimate Carbon Emissions Impact

To calculate gross annual carbon from burning coal to produce the above annual energy, multiply the annual energy produced by the carbon emission factor for coal.

Annual Energy Consumed	x	Carbon Emission Factor	=	Gross Annual Carbon
500 TJ		26.8 t C/TJ		t C/yr

= 13,400 tonnes (C) per year

Step 3: Adjust for Incomplete Oxidation

Correct for incomplete combustion by multiplying the total carbon emissions by the fraction of carbon oxidized.

Gross Annual Carbon Emissions	x	Fraction of Carbon Oxidized	=	Adjusted Annual Carbon Emissions
13,400 t C		98%		t C/yr

= 13,132 tonnes (C) per year

Step 4: Estimate Carbon Dioxide Emissions

Convert to CO_2 emissions by multiplying corrected carbon emissions by 44/12 (the molecular ratio of CO_2 to C.)

Adjusted Annual Carbon Emissions	x	CO_2/C Conversion Factor 44/12	=	Annual Carbon Dioxide Emissions
13,132 t(C)/yr		t(CO_2)/t(C)		t(CO_2)

= 48,150 tonnes of CO_2 per year

Total Project Impacts

Annual cement factory project emissions total 49,400 + 48,150 = **97,550 tonnes of CO_2 annually**. Assuming a project life of 30 years, total project emissions will be **2,926,500 tonnes of CO_2**.

Endnotes

[1] The project described here is fictitious and is presented for illustrative purposes only. It is not intended to resemble any actual or proposed projects.

References

McCulloch, A. Personal communication with Intergovernmental Panel on Climate Change. 1993. As cited in UNEP/OECD/IEA/IPCC 1995 (see below.)

Olivier, J. 1993. "Nitrous Oxide Emissions from Industrial Processes." In A.R. van Amstel (ed.), *Proceedings of an International IPCC Workshop on Methane and Nitrous Oxide: Methods in National Emissions Inventories and Options for Control.* Bilthoven, The Netherlands. As cited in UNEP/OECD/IEA/IPCC 1995 (see below.)

Reimer, R.A., R.A. Parrett and C.S. Slaten. 1992. *Abatement of N_2O Emission Produced in Adipic Acid.* Proceeding of Fifth International Workshop on Nitrous Oxide Emissions, Tsukuba, Japan. As cited in UNEP/PECD/IEA/IPCC 1995 (see below.)

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United Nations Environment Programme (UNEP), Organisation for Economic Co-operation and Development (OECD), International Energy Agency (IEA), Intergovernmental Panel on Climate Change (IPCC). 1995. *IPCC guidelines for National GHG Inventories, Volume 3: GHG Inventory Reference Manual.* IPCC: Bracknell, UK.

5 Land-Use Project Assessment Methodology: Forestry, Agriculture, and Land Management Projects

5.1 Introduction

The land-use sector encompasses a wide variety of activities that contribute to greenhouse gas (GHG) flux. Activities that alter the amount of vegetation on a parcel of land or the amount of organic carbon contained in soils, such as deforestation or forest plantation establishment, can result in either emissions or uptake of carbon dioxide (CO_2).[1] Activities that involve anaerobic decomposition of organic material (e.g., livestock digestion, wetland rice cultivation) result in methane (CH_4) emissions, and activities that add nitrogen to soils (e.g., fertilizer application) may result in nitrous oxide (N_2O) emissions. Open burning of vegetation, such as field burning of agricultural crop residues, releases all three GHGs, as well as other less important GHGs.

Most World Bank land-use projects involve more than one type of GHG-impacting activity. For example, an agroforestry project may, in addition to tree planting, have a livestock management component, while a watershed management project may include both tree planting and soil enhancement activities. For the purposes of GHG assessment, it is most straightforward to evaluate each activity within a project separately, and then sum the GHG impacts of all activities. Therefore, rather than structuring the remainder of this chapter to be consistent with World Bank project types, it is instead organized into four sections, each of which pertains to a broad category of GHG-producing/sequestering activities:

- **Forestry** (e.g., afforestation, reforestation, plantation, and forest conservation);
- **Agricultural Soils** (e.g., soil conservation, productivity improvement);
- **Livestock Management** (e.g., livestock digestion, livestock manure management); and
- **Other Land Management Activities** (e.g., land flooding, wetland drainage).

Each section presents basic GHG accounting concepts, methodologies, and default data for activities in that category, focusing on those activities that are most important in terms of GHG impacts. The methods and data are adapted from the latest version of the *IPCC Guidelines for National Greenhouse Gas Inventories* (UNEP/OECD/IEA/IPCC 1997). The Forestry section (5.2) covers activities that alter forest vegetation or soil carbon stocks, and provides methods for estimating resultant CO_2 emissions and uptake. Methods for estimating other GHG emissions from open burning of vegetation are also presented in this section.[2] The Agriculture section (5.3) covers agricultural soil management activities and wetland rice cultivation, and associated emissions and uptake of CO_2, and emissions of CH_4 and N_2O. Section 5.4 covers livestock management and associated CH_4 emissions from animal digestion and manure management. Finally, section 5.5 addresses the fluxes of CH_4 and N_2O that result from other land-use practices such as land flooding, wetland drainage, and conversion of forests and grasslands to managed lands. The activities that are addressed in this chapter, and the primary GHGs impacted by these activities, are presented by category in Exhibit 5-1.

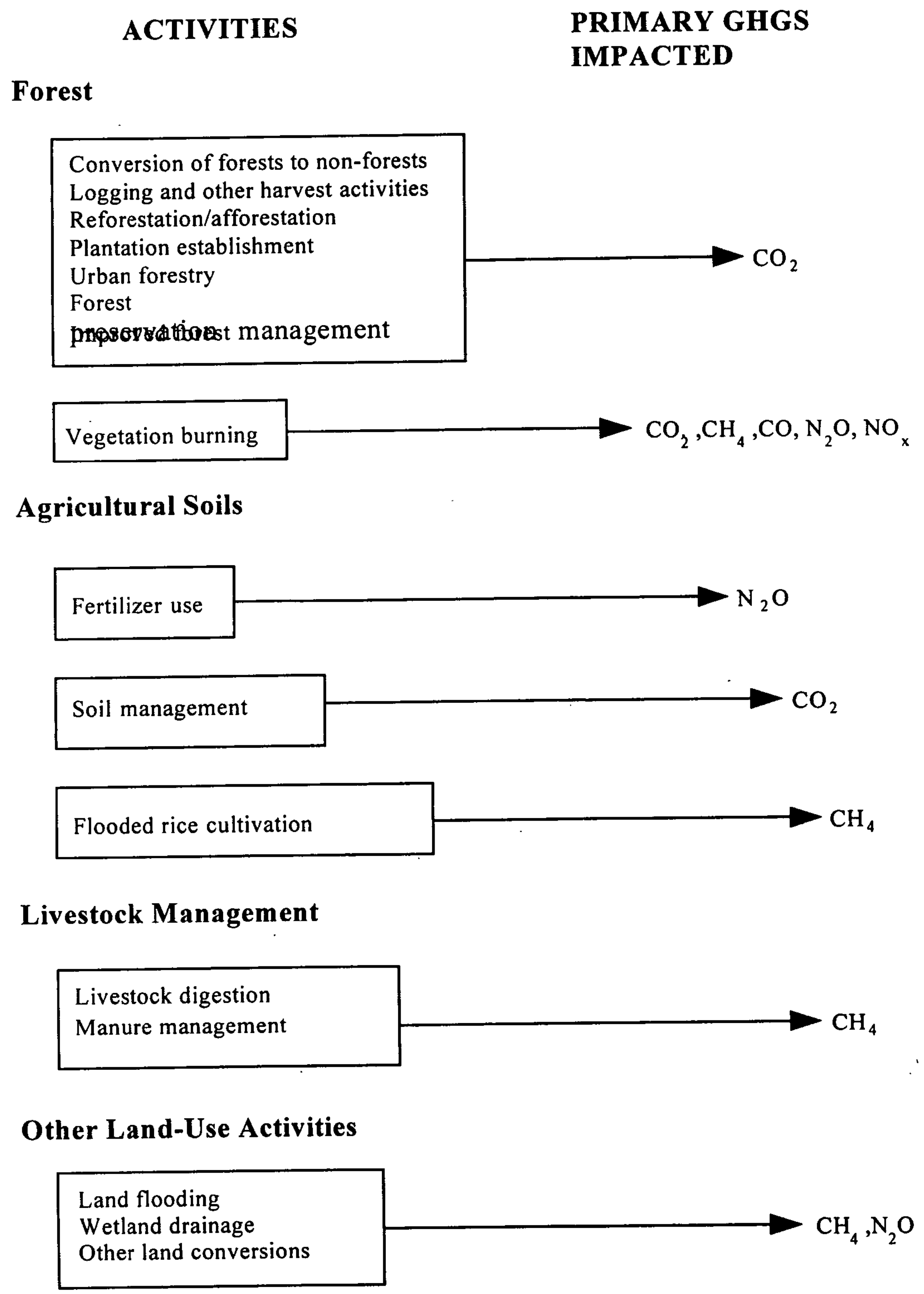
To estimate the GHG impacts of a particular World Bank project, the Task Manager must first determine which activities are contained within the scope of the project. This will depend, in part, upon the spatial and temporal boundaries that are "drawn" around the project. Defining these boundaries will not be straightforward for all types of projects because some projects may have GHG impacts beyond the physical boundaries of project activities (i.e., off-site GHG impacts). For example, a forest conservation project may displace forest clearing to other forested areas. Conversely, a project to improve agricultural productivity in one area may result in reduced deforestation in nearby areas. In addition, some projects may contain activities from more than one sector. For example, a fuelwood plantation project will involve both land-use and energy activities. In this case, GHG assessment methods from both the land-use and the energy chapters of this Handbook will need to be used.

Determining the appropriate time frame for GHG accounting can be particularly difficult for projects involving CO_2 flux (i.e., emissions or uptake), because CO_2 fluxes are not constant and carbon sequestration may not be permanent. An individual tree will grow (and sequester carbon) over varying rates during its lifetime, and growth can continue for many decades. However, once that tree is harvested, and is burned or allowed to decay, the carbon that has been sequestered will be released back to the atmosphere as CO_2. Therefore, the time frame chosen for determining project GHG impacts can have a significant effect on the result.

As is discussed in chapter 2. Basic Principles, this Handbook adopts a flexible approach for defining GHG boundaries. Because issues associated with project boundaries are highly dependent on the type and scope of project being undertaken, and there are innumerable types of conceivable World Bank projects, adoption of strict guidelines for boundary definition is not feasible. Therefore, Task Managers should define project GHG boundaries based on the reasons for which a project is undertaken. For example, if a fuelwood plantation project is planned to reduce harvests in an adjacent forest, then the project GHG boundaries should include this adjacent forest so the avoided GHG emissions (from the avoided harvest) are included in the GHG assessment. In addition, because the project is intended to produce biofuel, the time frame used for assessment should be long enough to include harvest and combustion of the wood produced by the plantation.

For those projects in which off-site or long-term GHG impacts are likely but cannot be quantified because of analytical uncertainties or limited resources for GHG assessment, the off-site or long-term impacts should at least be qualitatively assessed by the Task Manager. For example, an improved livestock management project may result in long-term market adjustments and emission impacts that are difficult to quantify (e.g., an increase in product supply, followed by a lowering of prices, and subsequent increase in demand and associated CH_4 emissions). In such cases, a brief description of potential off-site and/or long-term impacts is recommended.

Exhibit 5-1


ACTIVITIES
PRIMARY GHGS IMPACTED
Forest
Conversion of forests to non-forests
Logging and other harvest activities
Reforestation/afforestation
Plantation establishment
Urban forestry
Forest preservation
Improved forest management
CO_2
Vegetation burning
CO_2, CH_4, CO, N_2O, NO_x
Agricultural Soils
Fertilizer use
N_2O
Soil management
CO_2
Flooded rice cultivation
CH_4
Livestock Management
Livestock digestion
Manure management
CH_4
Other Land-Use Activities
Land flooding
Wetland drainage
Other land conversions
CH_4, N_2O

An additional issue that the Task Manager must address before undertaking project GHG analysis is the definition of the reference scenario -- the action or actions that most likely would have been undertaken in the absence of the project. As is described in chapter 2, the ultimate goal of project GHG estimation is to derive an estimate of the incremental GHG impacts of a project by comparing the net GHG emissions under the project scenario to those under a reference scenario. In some cases, the net GHG emissions under the project scenario will be zero, so the definition of the reference scenario will determine the net GHG benefits of a project. A simple example of this is a project in which actions are taken to prevent deforestation of a mature forest. Under the project scenario, stocks of vegetation remain constant so net GHG emissions are zero. However, under the reference scenario, deforestation results in emissions of CO_2, and possibly other GHGs. The incremental GHG impacts of this project are the avoided GHG emissions of the reference scenario.

The remainder of this chapter presents methodologies and default data for estimating the net GHG impacts of activities under the project and reference scenarios. Each section begins with a discussion of GHG concepts pertinent to the category of activities, followed by an overview of the general calculation methodologies. Tables of default data are provided for use in the calculations if site-specific information is not available. Also, case studies are presented to illustrate how the calculation methodologies would be applied to specific scenarios, as well as to illustrate how problematic issues that may arise in assessing GHG impacts of World Bank projects can be addressed.

5.2 GHG Assessment Methodology for Forestry Activities

5.2.1 General Concepts

Carbon, in the form of CO_2, is continuously cycled among several global carbon reservoirs: the atmosphere, the oceans, marine biota, terrestrial biota, soils and detritus, and sediments. These reservoirs are also referred to as carbon storage pools or stocks of carbon. Fluxes of CO_2 between terrestrial biota, soils and detritus, and the atmosphere, the three storage pools of interest here, occur via photosynthesis, respiration, and decay. When trees and other vegetation grow, CO_2 is withdrawn from the atmosphere through photosynthesis and carbon is stored in trunks, limbs, leaves, stems, and roots. This process is referred to as CO_2 uptake or carbon sequestration. Respiration of vegetation and decay of organic matter in soils and detritus release stored carbon back to the atmosphere as CO_2. Carbon stored in vegetation may also be released to the atmosphere through combustion -- a rapid form of decay in which the carbon contained in the vegetation is oxidized and released as CO_2. The release of carbon to the atmosphere is referred to as CO_2 emissions.

While trees are growing, they act as a sink of carbon.[3] In other words, annual carbon sequestration through photosynthesis exceeds annual CO_2 emissions from respiration and decay, and the stock of carbon is increasing over time. Mature forests are typically assumed to be stable in terms of net carbon accumulation, i.e., photosynthetic gains are balanced by losses through respiration and decay, and net emissions of CO_2 are zero. Therefore, undisturbed mature forests are neither a source nor a sink of CO_2; instead, they are a stable storage pool, or stock, of carbon.

The amount of organic carbon contained in soils depends on the balance between organic matter inputs (decayed detritus and roots) and soil carbon oxidation. Generally, in an undisturbed mature forest, these processes are in equilibrium, and soil carbon stocks are stable. However, in a young forest, organic inputs typically exceed oxidation rates, and soil carbon stocks accumulate over time until an equilibrium between carbon inputs and oxidation is reached. Rates of organic matter inputs and soil carbon oxidation depend largely on climatic and soil conditions.

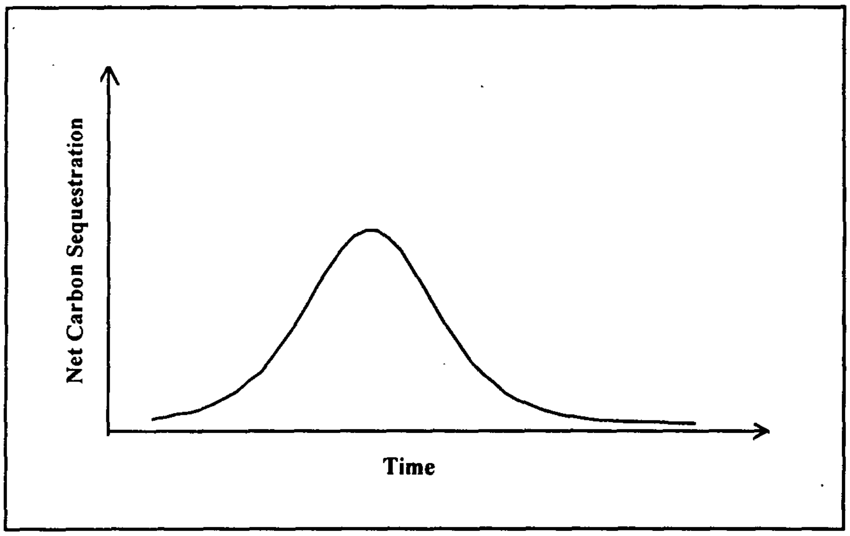
Rates of vegetation growth (and hence rates of carbon sequestration), and rates of vegetation decay (and hence rates of CO_2 emission) also depend on several variables. In general, an individual tree (or a forest) grows slowly at first, then rapidly, and then slowly again until it reaches maturity and growth slows to zero (Exhibit 5-2). Rates of growth depend not only on the age of a tree, but also on climatic variables, especially rainfall. In general, for a given species, growth rates increase with increasing annual rainfall. Growth rates also vary among species; in general, hardwood species grow more slowly than softwood species. Other factors, such as growing season length and soil conditions, also affect growth rates.

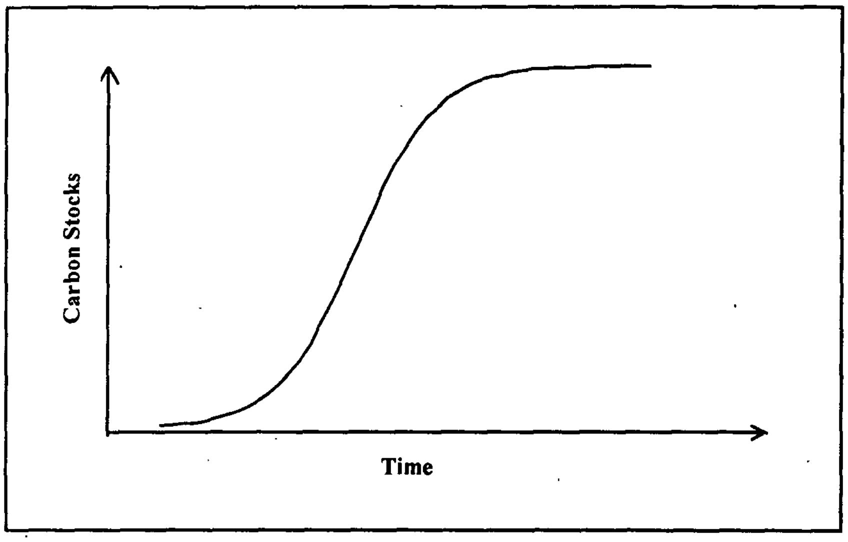
Rates of vegetation decay depend primarily upon the fate of vegetation. If wood is burned (e.g., to clear lands, or to supply energy), CO_2 emissions are immediate. If wood is left on the ground to decay (e.g., as litter, or as debris after forest clearing or logging), carbon is oxidized more slowly and released to the atmosphere over several to many years. The rate of decay will depend on factors such as temperature, rainfall, and size and geometry of the debris. If wood is harvested for use in products such as paper or lumber, many years may pass before the products are discarded and allowed to decay.

Forestry activities (deforestation, plantation establishment, logging, urban tree planting, etc.) can alter rates of vegetation growth, decay, and soil carbon oxidation, and consequently the amount of carbon stored in terrestrial biota, soils and detritus, and the atmosphere. For example, when a forest area is cleared and converted to another use such as cropland, emissions of CO_2 will be increased through decay and/or burning of the cleared vegetation, and also possibly due to soil carbon oxidation. Eventually the CO_2 flux will reach a new steady state in which photosynthesis associated with agricultural production is equal to crop respiration and decay. However, the carbon stocks on that parcel of land will have been reduced because there has been a net flux to the atmosphere. Conversely, planting trees on idle land will increase carbon sequestration, and may also cause soil carbon stocks to increase. Eventually, assuming no harvest, fluxes to and from the atmosphere will reach equilibrium, and carbon stocks will stabilize at a level higher than when the land was idle. Terrestrial carbon stocks will have increased because there has been a net flux from the atmosphere to the biosphere.

Whether forest harvest results in net CO_2 emissions depends on the fate of the harvested wood and the land, as well as the time frame used for analysis. For example, consider a ten-year harvesting project in which the land is left idle after harvest, the harvested wood is used to produce short-term wood products such as paper, and slash remaining on site decays quickly. In this case, CO_2 emissions from decay of products and slash will most likely exceed carbon sequestration due to unassisted regrowth during the project lifetime of ten years, and the project will result in net emissions. If instead, the ten-year project consists of reforesting the land after harvest and using the harvested wood in long-term wood products, such as lumber, that are not expected to decay for over 100 years, then carbon sequestration due to assisted regrowth will likely exceed CO_2 emissions from decay of products and slash during the project lifetime. In this case, the project will result in net sequestration. As these examples illustrate, project parameters, especially lifetime, should be defined carefully before undertaking an assessment of project impacts on CO_2 flux.

Exhibit 5-2 Generic Tree Growth





Note: The upper graph illustrates vegetation growth rates, or net carbon sequestration rates, for a generic tree or forest, from planting to maturity. The lower graph illustrates the accumulation of vegetation carbon in this generic tree or forest over the same time period. At maturity, growth rates slow to zero, and carbon stocks reach a steady state.

Although CO_2 is the primary GHG affected by forestry activities, fluxes of other GHGs may also be impacted. When vegetation is burned, such as during land preparation prior to tree planting, CH_4, N_2O, CO, NO, and non-methane volatile organic compounds (NMVOCs), in addition to CO_2, are released during combustion. Unlike CO_2 emissions, which may be offset by subsequent carbon sequestration, emissions of these other gases are always net emissions. Although combustion emissions of CH_4, N_2O, CO, NO, and NMVOCs are likely to be minor for most World Bank projects, a basic methodology for their estimation is presented below in section 5.2.3. Forestry activities, especially those that change land-uses, can also result in enhanced or diminished CH_4 and N_2O fluxes from soils (relative to fluxes that would occur naturally, or without human interference). These other GHG impacts are discussed briefly in section 5.5. However, scientific uncertainty precludes development of generic methods for their assessment.

5.2.2 Estimation of CO_2 Impacts of Forestry Activities

Net CO_2 emissions resulting from forestry activities can be calculated using one of two approaches: either the stock approach, or the flow approach. The stock approach is used when annual flux data are not available, or when information on the timing of CO_2 impacts is not needed. Carbon stocks are assessed at the beginning of a project and at the end, and the net change in carbon stocks is assumed to equal net CO_2 emissions from project activities. The flow approach consists of an assessment of annual CO_2 emissions and annual carbon sequestration associated with project activities, which are then summed over all project years to yield total net emissions. The Task Manager should select the approach that best fits the data that are available, as well as most effectively meets the needs of the assessment. The stock approach and the flow approach are described below in detail in sections 5.2.2.1 and 5.2.2.2, respectively.

Several elements are common to both the stock and the flow approaches. Regardless of the calculation approach selected, the Task Manager should begin the CO_2 assessment process by completing the following steps.

1. Compile a list of all forestry activities and the associated stocks and flows of carbon that are likely to be impacted by those activities under the project scenario and the reference scenario.[4]

2. Identify the land type(s) and boundaries of the area(s) over which these activities will occur and/or influence the flux of CO_2.

3. Identify the time frame(s) over which these activities will influence the flux of CO_2.

In both approaches, carbon stocks are divided into three components: aboveground biomass, belowground biomass, and organic soil carbon. The term "biomass" refers to living and dead organic material. Aboveground biomass is all the vegetation above the ground surface, and belowground biomass is all the vegetation below (essentially roots). Each component is tracked separately in the calculations because the CO_2 emission and carbon sequestration rates resulting from any particular forestry activity can vary significantly among stock components. For example, if a forest area is cleared by slash-and-burn methods, most of the aboveground biomass carbon will be released to the atmosphere immediately, while oxidation of the belowground biomass and soil carbon stocks will occur much more slowly, if at all. Although the CO_2 estimation methods contained in this section of the Handbook address all three components, the impacts of forestry activities on CO_2 flux associated with changes in belowground biomass and soil carbon are, in some cases, quite uncertain. Therefore, if reliable data are lacking, the Task Manager may want to ignore these two stocks of carbon in the calculation of project impacts.

Both the stock and flow approaches adopt a simplifying assumption that is consistent with the IPCC inventory methodology (UNEP/OECD/IEA/IPCC 1997):

- All of the carbon contained in harvested aboveground biomass is assumed to be released to the atmosphere in the year of harvest, regardless of the use or destination of the biomass.

In reality, the rate at which this carbon is released depends upon the biomass use or destination. For example, when timber is harvested, a portion of the biomass may remain on site as slash and decay over a period of several years, or may be burned on site, which immediately releases CO_2 and other GHGs to the atmosphere. Likewise, if the timber is harvested for fuelwood, it may be combusted soon after harvesting, releasing CO_2 and other GHGs. Products made from the timber will store the carbon until the product is disposed of. For example, paper may store carbon for five or more years, and lumber used in construction may store carbon for up to 100 or more years. Not accounting for the variable decay rates of harvested biomass may distort the timing of CO_2 emissions, but should not significantly distort the magnitude of the emissions that ultimately result from project activities. However, if a project involves harvest of wood for use in products that are unlikely to be discarded and allowed to decay at any time in the foreseeable future, a Task Manager may want to consider treating this harvested carbon as a stock transfer rather than an emission. In this case, the carbon is assumed to be transferred to a permanent storage pool.

Task Managers should use site-specific data to the extent that such data are available. This Handbook provides default values that may be used when site-specific data are not available, or when only rough estimates of CO_2 impacts are desired. The default values are organized according to forest type: tropical, temperate, or boreal. Tropical forests are further classified according to annual rainfall and other ecological conditions, as is shown in Exhibit 5-3. If the default data provided here are used in CO_2 calculations, Task Managers should familiarize themselves with this classification system so appropriate default values are chosen.

The methods and data presented in this section adhere to the IPCC's conventions regarding units of measurement for the quantity, growth rate, and carbon content of biomass as well as for land area.

- Biomass quantities are measured in units of metric tonnes of dry matter (t dm). If the project's biomass data are collected on a wet-weight basis, the data should be converted to a dry-weight basis by subtracting the weight contributed by the moisture content of the biomass.

- Commercial wood harvest statistics are typically measured in units of cubic meters (m^3), and are often provided for the commercial portion of biomass only (i.e., roundwood). In this case, the data need to be converted to mass units (t dm), and need to be adjusted to account for the total quantity of biomass removed, including slash. Conversion to mass units is accomplished by multiplying by the wood density. The density of wood varies a great deal among species; Dixon et al. (1991) list densities that range from 0.31 to 0.86 t dm/m^3. If densities for the dominant species are not readily available, default values of 0.65 t dm/m^3 for deciduous trees and 0.45 t dm/m^3 for conifers can be applied. To account for the non-commercial biomass (e.g., branches and small trees) removed during harvest, an expansion ratio should also be applied the commercial harvest. Default expansion ratios are as follows: 1.75 for undisturbed forests, and 1.90 for logged forests (Brown et al. 1989, and ECE/FAO 1992, as cited in UNEP/OECD/IEA/IPCC 1997)..

- Land area is measured in hectares (ha). To convert from acres to hectares, apply the conversion ratio of 0.405 ha/acre. To convert from square meters (m^2) to hectares, apply the conversion ratio of 10^{-4} ha/m^2.
- Biomass densities (the stock of biomass on a unit area of land) are measured in tonnes of dry matter per hectare (t dm/ha). Default data for the densities of aboveground biomass stocks in tropical, temperate, and boreal forests are presented in Exhibits 5-4 through 5-6. In the absence of site-specific data, the density of aboveground biomass stocks on grassland and agricultural land is assumed to be 10 t dm/ha.

- The rate of biomass accumulation is measured in units of tonnes of dry matter per hectare per year (t dm/ha-yr). Default data for aboveground biomass accumulation rates in tropical, temperate, and boreal forests as well as plantations are presented in Exhibits 5-7 and 5-8.

- There are only limited data on belowground biomass stocks. Belowground biomass stocks in forests can be estimated by applying root-to-shoot ratios (R/S) to aboveground forest biomass stocks. Default R/S values (both averages and ranges) are provided in Exhibit 5-9. The R/S ratios can also be used to estimate increases in belowground biomass stocks associated with increases in aboveground biomass.

- Biomass densities and accumulation rates, which are measured in units of t dm, need to be converted to units of carbon (C) to estimate CO_2 impacts. This is accomplished by multiplying by the carbon content of biomass, which is measured in units of tonnes of carbon per tonne of dry matter (t C/t dm). Biomass carbon contents do not vary significantly among tree species, but they do vary between woody and leafy biomass. The carbon content of woody biomass averages about 0.5 t C/t dm, while the carbon content of leafy biomass and grasses averages about 0.45 t C/t dm. The bulk of the biomass (on a mass basis) involved in forestry projects will be woody biomass, so a default value of 0.5 t C/t dm may be used.

- Soil carbon contents are measured in units of tonnes of carbon per hectare (t C/ha). Very rough default values for tropical, temperate, and boreal forests are provided in Exhibits 5-10 and 5-11. General default values for grasslands are 60 t C/ha for tropical systems, and 70 t C/ha for temperate systems. In the absence of site-specific data, Task Managers can assume that conversion of forests to cultivated lands in the tropics results in loss of 40-50% of the soil carbon; while conversion of forests to cultivated lands in temperate and boreal regions results in loss of 30-40% of the soil carbon. However, these default values are only meant to provide very rough approximations. The data on the effects of land management and land-use change on soil carbon stocks are very limited, so Task Managers may want to skip this component if site-specific data are not available.

The methods presented in this section also follow the IPCC sign conventions for expressing GHG impacts. GHG emissions are assigned a positive value, and carbon sequestration a negative value. However, an increase in carbon stocks is assigned a positive value, and a decrease in carbon stocks a negative value. This convention results in the requirement that when converting an estimated change in carbon stocks to net emissions, the carbon stock change is multiplied by a negative one (-1).

EXHIBIT 5-3
TYPES OF TROPICAL FORESTS AND REGIONAL FOREST FORMATIONS

Types of tropical forests[a]						
	Wet	Moist with short dry season	Moist with long dry season	Dry	Montane Moist	Montane Dry
	R ≥ 2000	2000>R>1000		R<1000	R>1000	R<1000
Forest	Mainly evergreen	Mainly moist deciduous	Mainly dry deciduous	Very dry deciduous	Mainly evergreen	Mainly dry deciduous
Typical regional forest formations:						
Africa	Lowland rain forests	Lowland evergreen to semi-ever-green forests	Dry deciduous forests and miombo woodlands	Deciduous forests and woodlands. Very dry savanna and steppe	Montane evergreen forests	Scrub forests and evergreen to semi-evergreen thickets
Asia	Tropical lowland evergreen rain forests	Dense semi-deciduous or deciduous forests	Dry deciduous forests	Low deciduous forests. Thorn forests	Tropical and wet and moist forests	Dry evergreen forests or pseudo-steppic vegetation
America	Ombrophilous forests	Evergreen seasonal forests.	Tropical and subtropical forests Cerrados or pantanal	Open deciduous forests	Tropical evergreen and/or seasonal forests	Dry deciduous forests or shrub savanna. Arid subdesertic matorrales
Open formations of the different climatic zones:						
Open Forest	Mainly evergreen degraded	Mainly moist deciduous	Mainly woodlands and tree savanna	Dry woodlands and tree savanna	Mainly degraded evergreen and seasonal	Mainly dry savannas

R= annual rainfall in mm/yr

Source: UNEP/OECD/IEA/IPCC (1997), and references cited therein.

Note: [a] The ecological conditions which characterise these main vegetation cover classes are:

Wet - Evergreen dense forests which receive more than 2000 mm per year rainfall evenly throughout the year.

Moist with short dry season - Deciduous forests, characterised by a short dry season (<4-5 months), and rainfall 1000-2000 mm per year.

Moist with long dry season - Woodlands and open forests, characterised by a long dry period (>5 months), and rainfall 1000-2000 mm per year.

Dry- Woodlands and tree savannas which receive less than 1000 mm per year of rainfall, very seasonally distributed.

Montane moist and dry- Main features of this zone are altitude above 1000 metres and rainfall above and below 1000 mm per year respectively.

EXHIBIT 5-4
AVERAGE ABOVEGROUND BIOMASS DENSITY ESTIMATES FOR TROPICAL FORESTS BY CLIMATIC ZONE
(Tonnes Dm/Ha)

Tropical forests	Wet	Moist with short dry season	Moist with long dry season	Dry	Montane Moist	Montane Dry
	R > 2000	2000>R>1000		R<1000	R>1000	R<1000
Africa	300	140	60-90[a]	20-55[a]	105	40
Asia:						
Continental	225	185	100	75	190	no data
Insular	275	175	no data	little to no forest exists	255	no forest exists
America	295	no data	90	105	150	50

R= annual rainfall in mm/yr

Source: UNEP/OECD/IEA/IPCC (1997), and references cited therein.

Note: Estimates were derived from a model in a geographic information system and calibrated with reliable forest inventory data (Iverson et al., 1994) or from direct measurements [a](P. , pers. comm., 1996). Multi-date inventories were brought to a common year of about 1980. The estimates do not distinguish between primary or secondary forests but represent values averaged over the whole forested area in a given climatic zone in a given tropical region. These average values can include forests in all successional states, from mature or undisturbed to young secondary. Additional country-specific biomass estimates are presented in Exhibit 5-5. Data are from Brown et. al. (1993) for Asia; Brown and Gaston (1995) for Africa; and S. Brown (pers. comm., 1995) for America.

EXHIBIT 5-5
ABOVEGROUND BIOMASS DENSITY ESTIMATES FOR VARIOUS TROPICAL FOREST TYPES BY COUNTRY
(Tonnes Dm/Ha)

Country	Forest Type	Climatic Zone	Aboveground Biomass
Africa			
Benin	Closed forest Tree savanna	Dry Dry	175 96
Botswana[a]	Mixed tree savanna	Dry-long dry season	19
Burkina Faso (National)	Degraded tree savanna	Dry- long dry season	20
Cameroon	Primary	Very moist	310
Gambia (National)	Gallery forest Closed woodland Open woodland Tree savanna	Moist- dry season Dry Dry Dry	140 97 50 28
Ghana	Closed forest	Moist-short dry season	395
Guinea (National)	Mixed; closed Open, secondary	Moist-long & short dry	135
Mozambique	Dense forest Dense forest Dense forest	Moist- long dry Moist- long dry Dry- long dry season	120 130 70
Zambia[a]	Woodland-miombo Woodland-miombo	Moist-long dry season Dry-long dry season	91 81
Zimbabwe[a]	Woodland-miombo	Dry-long dry season	29
Asia			
Bangladesh	Closed -large crowns Closed -small crowns Disturbed closed Disturbed open	Very moist Very moist Very moist Very moist	206-210 150 190 85
Cambodia	Dense Semi-dense Secondary Open Open Well to poorly stocked Evergreen Deciduous	Moist-short dry Moist-short dry Moist-short dry Moist-short dry Moist-long dry Moist-long dry Moist-long dry	295 370 190 160 70 100-155 120
India	High to low volume Closed Forest fallow	Dry Dry	44-81 16

EXHIBIT 5-5 (CONT.)
ABOVEGROUND BIOMASS DENSITY ESTIMATES FOR VARIOUS TROPICAL FOREST TYPES BY COUNTRY
(Tonnes Dm/Ha)

Country	Forest Type	Climatic Zone	Aboveground Biomass
Asia - (cont)			
Malaysia-Peninsular (National)	Superior/moderate hill Poor hill Upper hill Disturbed hill Logged hill Forest fallow Freshwater swamp Disturbed freshwater swamp Logged freshwater swamp	Very moist Very moist Very moist Very moist Very moist Very moist Very moist Very moist Very moist	245-310 180 275 200 180 140 220 285 185
Malaysia- Sarawak	Mixed dipterocarps-dense stocking, flat to undulating terrain Mixed dipterocarps-dense stocking, mountainous Mixed dipterocarps- medium stocking, flat to mountainous	Very moist Very moist Very moist	325-385 330-405 280-330
Myanmar	Evergreen Mixed deciduous Indaing forest	Moist-short dry Moist-short dry Moist-short dry	60-200 45-135 10-65
Philippines	Old-growth dipterocarp Logged dipterocarp	Very moist Very moist	370-520 300-370
Sri Lanka	Evergreen-high yield Evergreen-medium yield Evergreen-low yield Evergreen-logged Secondary	Very moist Very moist Very moist Very moist Very moist	435-530 365-470 190-400 255 280
Thailand	Degraded dry evergreen	Moist-long dry	85
America -	All forests are located in the wet/very moist climatic zone except where indicated.		
Bolivia	Closed forest		230
Brazil	Closed forest		315
Ecuador	Closed forest		182
French Guyana	Closed forest Riparian forest Savanna forest		309 275 205
Guatemala	Closed forest		242

EXHIBIT 5-5 (CONT.)
ABOVEGROUND BIOMASS DENSITY ESTIMATES FOR VARIOUS TROPICAL FOREST TYPES BY COUNTRY
(Tonnes Dm/Ha)

Country	Forest Type	Climatic Zone	Aboveground Biomass
America - (cont.)	All forests are located in the wet/very moist climatic zone except where indicated.		
Guyana	Closed forest		254
	Logged forest		190
	Wallaba forest-seasonal		145
	Mixed forest		275
	Low mixed forest		192
	Liana forest		125
	Wallaba forest		148
	Wallaba forest on white sands		405
Nicaragua	Orifino forest		240
	Lowland mixed		235
	Mature forest		240
	Secondary		183
Panama	High density-mixed		239-366
	Low density-mixed		169-245
	Campnosperma forest -high density		860
	Campnosperma forest -low density		470
	High density-mixed		186-252
	Low density-mixed		118-143
Peru	Primary		210
	Lightly logged		192
	Heavily logged		125
	Late secondary		140
	Young secondary		20
	Flooded secondary		195
	Low forest		155
Surinam	Upland forest		255
	Small crown-upland		136
	Savanna forest		195
	Riparian forest		217
	Liana forest		120
	Wallaba forest		250
Venezuela	Semi-deciduous-dry		78
	Closed forest		230

Source: UNEP/OECD/IEA/IPCC (1997), and references cited therein.

Note: All biomass estimates were derived from either reliable forest inventory data for subnational to national forest areas (sources of inventories and details of methods used to convert to biomass are given in Brown (1997), or from direct measurements [a](P. Frost, pers. comm., 1996).

EXHIBIT 5-6
AVERAGE ABOVEGROUND BIOMASS DENSITY ESTIMATES FOR TEMPERATE AND BOREAL FORESTS
(Tonnes Dm/Ha)

Temperate Forests	Coniferous	220 - 295
	Broadleaf	175 - 250
Boreal Forests	Mixed broadleaf/coniferous	40 - 87
	Coniferous	22 - 113
	Forest-tundra	8 - 20

Source: UNEP/OECD/IEA/IPCC (1997), and references cited therein.
Note: Temperate forest estimates from Whittaker and Likens (1973) and Houghton et al. (1983). Total biomass estimates were converted to aboveground biomass by multiplying by 0.83 (Leith and Whittaker, 1975). Boreal forests biomass estimates are from Bazilevich (1993), Finnish Forest Research Institute (1995), Kokorin and Nazarov (1995a), and Isaev et al. (1993). 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). Most temperate and boreal countries have their own national estimates of biomass densities for forests which should be used. These default values are very rough estimates and are provided for comparison only.

EXHIBIT 5-7
ANNUAL AVERAGE ABOVEGROUND BIOMASS GROWTH BY NATURAL REGENERATION
(Tonnes Dm/Ha)

Tropical Forests

	Wet	Moist with Short Dry Season	Moist with Long Dry Season	Dry	Montane Moist	Montane Dry
	R ≥ 2000	2000>R>1000		R≤1000	R>1000	R<1000
Africa						
≤20 years	10	5.3	2.3-2.5	0.8-1.5	5	2
>20 years	2.5	1.3	0.6-3.0	0.2-1.6	1	0.5
Asia:						
Continental						
≤20 years	11	9	6	5	5	no data
>20 years	3	2	1.5	1.3	1	
Insular	13					
≤20 years	3.4	11	little to	little to	12	none exist
>20 years		3	none exist	none exist	3	
America						
≤20 years	10	no data	4	4	5	1.8
>20 years	2.6		1	1	1.4	0.4

R= annual rainfall in mm/yr

Source: UNEP/OECD/IEA/IPCC (1997), and references cited therein.

Note: Growth rates are derived by assuming that tropical forests grow to 50% of undisturbed biomass in the first 20 years. All forests are assumed to regrow to 100% of undisturbed conditions in 100 years. Undisturbed forest biomass values are from Brown et al. (1993) for Asia, Brown and Gaston (1995) for Africa, and S. Brown (pers. comm., 1996) for America. Assumptions on the growth rates in different time periods are derived from Brown and Lugo (1992). Values marked with * are from P. Frost (pers. comm., 1996).

Temperate Forests		0-20 Years	20-100 Years
	Coniferous	3.0	3.0
	Broadleaf	2.0	2.0

Boreal Forests		0-20 Years	20-150 Years
	Mixed Broadleaf-Coniferous and Broadleaf	0.7-2.0	0.7-6.4
	Coniferous	0.5-1.9	0.5-5.0
	Forest-tundra	0.2-0.5	

Source: UNEP/OECD/IEA/IPCC (1997), and references cited therein.

Note: ALL OF THESE REGIONAL AVERAGE GROWTH RATES SHOULD BE CONSIDERED INDICATIVE ONLY. Temperate and boreal forests actually require considerably longer than 100 years to reach thebiomass 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 thebiomass 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. Nabuurs and Mohren (1993) 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).

EXHIBIT 5-8
AVERAGE ANNUAL ACCUMULATION OF DRY MATTER AS BIOMASS IN PLANTATIONS

Forest Type		Annual Increment in Biomass (tonnes dm/hectare/year)
Tropical	*Acacia* spp.	15.0
	Eucalyptus spp.	14.5
	Tectona 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

Source: UNEP/OECD/IEA/IPCC (1997), and references cited therein.

Note: These are average accumulation rates over expected plantation lifetimes derived from Brown et al. (1986) and Farnum et al. (1983); actual rates will vary depending on the age of the plantation. The data for the temperate species are based on measurements in the United States. Data on other species, and from other regions, should be supplied 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.

EXHIBIT 5-9
ROOT-TO-SHOOT RATIOS FOR BELOWGROUND BIOMASS

Forest Type		Root-to-Shoot Ratio Average (Range)
Tropical	Moist forest growing on spodosols	1.5 (0.7 - 2.3)
	Lowland very moist forest	0.13 (0.06 - 0.33)
	Montane moist forest	0.22 (0.11 - 0.33)
	Deciduous forest (e.g., tropical dry and seasonal moist forest)	0.47 (0.23 - 0.85)
Temperate	Coniferous	0.20
	Broadleaf	0.25
Boreal	Coniferous	0.25 (0.20 - 0.30)
	Broadleaf	0.20 (0.15 - 0.25)
	Forest-tundra	0.35 (0.30 - 0.50)

Source: UNEP/OECD/IEA/IPCC (1997), and references cited therein.

Note: The root-to-shoot ratios were derived from Brown (1997) for tropical forests, Cooper (1983) for temperate forests, and Isaev et al. (1993) for boreal forests. Estimation of CO_2 emissions from belowground biomass after clearing has been identified as an area of future work.

EXHIBIT 5-10
CARBON IN SOILS IN TROPICAL FORESTS
(Tonnes Carbon/Ha)

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

Source: UNEP/OECD/IEA/IPCC (1995), and references cited therein.

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.

EXHIBIT 5-11
CARBON IN SOILS IN TEMPERATE AND BOREAL FORESTS
(Tonnes Carbon/Ha)

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

Source: UNEP/OECD/IEA/IPCC (1995), and references cited therein.

Note: These values are derived from Schlesinger (1977) as cited in Houghton et al. (1983), and from Houghton et al. (1987). Alternate values for soil carbon in 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.

5.2.2.1 Stock Approach

The stock approach operates under the assumption that any change in terrestrial carbon stocks (i.e., carbon stored in aboveground or belowground biomass or soil) represents an equal and opposite change in atmospheric carbon, in the form of CO_2. Therefore, by measuring the net change in carbon stocks resulting from the project, the Task Manager can estimate the project's total CO_2 impacts over its lifetime. This is accomplished by estimating the difference between carbon stocks at the beginning of the project and at the end of the project. With this approach, it is important for the Task Manager to define the end date of the project as the point at which carbon stocks have reached equilibrium. Otherwise, the calculations may not capture all of the CO_2 flux resulting from the project. For example, the lifetime of a tree planting project should be defined such that the project end date is the date at which the trees no longer sequester additional carbon, i.e., photosynthetic gains are balanced by losses through respiration and decay, and net annual sequestration is zero.

The stock approach involves the following formulas, which are applied separately to the project and reference scenarios when appropriate:

Formula 5.1 Estimate the Initial Carbon Stocks in the Project Area

Total Project Area	x	[(Initial Biomass Density	x	Biomass Carbon Content)	+	Soil Carbon Content]	=	Initial Carbon Stock
(ha)		(t dm/ha)		(t C/t dm)		(t C/ha)		(t C)

Formula 5.2 Estimate the Final Carbon Stocks in the Project Area

Total Project Area	x	[(Final Biomass Density	x	Biomass Carbon Content)	+	Soil Carbon Content]	=	Final Carbon Stock
(ha)		(t dm/ha)		(t C/t dm)		(t C/ha)		(t C)

Formula 5.3 Estimate the Total Change in Carbon Stocks and Associated CO_2 Emissions in the Project Area

Final Carbon Stock	–	Initial Carbon Stock	=	Net Change in Carbon Stock
(t C)		(t C)		(t C)

Net Change in Carbon Stock	x	Molecular/Atomic Weight Ratio	x	(-1)	=	Net CO_2 Emissions (+) or Sequestration (-)
(t C)		(t CO_2/t C)				(t CO_2)

- *Total Project Area:* The total project area is defined as the area over which the project impacts CO_2 fluxes. If a project area involves multiple land types and/or multiple activities, the project area should be divided into appropriate parcels and these formulas should be applied separately to each parcel.

- *Biomass Density:* Biomass density should include either aboveground biomass stocks only, or both aboveground and belowground biomass stocks, depending on data availability.

- *Biomass Carbon Content:* In the absence of site-specific data, a default value of 0.5 t C/t dm should be used.

- *Molecular/Atomic Weight Ratio:* To convert t C to t CO_2, apply the ratio of 44 t CO_2/12 t C.

- *Net CO_2 Emissions/Sequestration*: CO_2 emissions are assigned a positive value, and carbon sequestration a negative value. An increase in carbon stocks corresponds to net carbon sequestration or net CO_2 uptake; conversely, a decrease in carbon stocks corresponds to net CO_2 emissions. The factor of (-1) is applied in this formula to maintain a consistent sign convention.

Case Study 5-1 illustrates the application of the stock approach in order to measure the GHG benefits generated by a forest preservation project.

Case Study 5-1: Forest Preservation Project

A World Bank project proposes to undertake measures to indefinitely protect 500 ha of endangered mature tropical forest in a Latin American country. A study of past land-use trends and current increases in the demands for timber and agricultural land indicates that in the absence of the project, the entire project area is likely to be deforested and converted to agricultural land within ten years. The current aboveground biomass stock on the project area is estimated to be 220 t dm/ha, the belowground biomass stock is 330 t dm/ha, and the soil carbon content is 115 t C/ha. Because the forest is mature, no change in carbon stocks is expected to occur if the forest is preserved. Agricultural land near the project area was found to have an aboveground biomass stock of 10 t dm/ha, a belowground biomass stock of 5 t dm/ha, and a soil carbon content of 63 t C/ha. The biomass carbon content is assumed to be 0.5 t C/t dm.

Under the project scenario, the mature forest is protected from conversion indefinitely. Because the mature forest is in equilibrium with regard to carbon emissions and sequestration, no net change in carbon stocks is anticipated. Therefore, this project will generate zero gross emissions of CO_2 and zero gross sequestration of carbon.

Under the reference scenario, the initial biomass density is reduced from 550 t dm/ha (= 220 t dm/ha of aboveground biomass + 330 t dm/ha of belowground biomass) to 15 t dm/ha (= 10 t dm/ha of aboveground biomass + 5 t dm/ha of belowground biomass), and the initial soil carbon content is reduced from 115 t C/ha to 15 t C/ha. To calculate carbon emissions under the reference scenario, Formulas 5.1 through 5.3 are applied as follows:

Total Project Area	x	[(Initial Biomass Density	x	Biomass Carbon Content	+	Soil Carbon Content]	=	Initial Carbon Stock
500 ha		550 t dm/ha		0.5 t C/t dm		115 t C/ha		195,000 t C

Total Project Area	x	[(Final Biomass Density	x	Biomass Carbon Content	+	Soil Carbon Content]	=	Final Carbon Stock
500 ha		15 t dm/ha		0.5 t C/t dm		63 t C/ha		35,250 t C

Final Carbon Stock	–	Initial Carbon Stock	=	Net Change in Carbon Stock
35,250 t C		195,000 t C		-159,750 t C

Net Change in Carbon Stock	x	Molecular/Atomic Weight Ratio	x	(-1)	=	Net CO_2 Emissions
-159,750 t C		44 t CO_2/12 t C				585,750 t CO_2

Although the project does not generate CO_2 emissions or sequester carbon directly, it does produce a GHG benefit by preventing emissions of 585,750 t CO_2.

5.2.2.2 Flow Approach

The flow approach determines a project's net CO_2 impact by accounting for CO_2 emissions and carbon sequestration on an annual basis throughout the project lifetime. Unlike the stock approach, the flow approach enables the Task Manager to determine the timing of the project's GHG impacts as well as their magnitude. However, the flow approach is more complex than the stock approach and requires the availability of data on annual CO_2 emissions and carbon sequestration resulting from all land-use activities under the project and reference scenarios. The application of the flow approach to the calculation of net CO_2 emissions and sequestration is discussed below.

The flow approach involves the following formulas, which are applied separately to the project and reference scenarios when appropriate:

Formula 5.4 Estimate the Annual Sequestration of Carbon from Biomass Growth in the Project Area

Total Project Area (ha)	x	Annual Biomass Growth Increment (t dm/ha-yr)	x	Biomass Carbon Content (t C/t dm)	x	(-1)	=	Annual Biomass Carbon Sequestration (t C/yr)

Formula 5.5 Estimate the Annual Accumulation of Soil Carbon in the Project Area

Total Project Area (ha)	x	Rate of Soil Carbon Accumulation (t C/ha-yr)	x	(-1)	=	Annual Soil Carbon Accumulation (t C/yr)

Formula 5.6 Estimate the Annual Emissions of Biomass Carbon in the Project Area

Total Project Area (ha)	x	Annual Biomass Harvested/Destroyed (t dm/ha-yr)	x	Biomass Carbon Content (t C/t dm)	=	Annual Biomass Carbon Emissions (t C/yr)

Formula 5.7 Estimate the Annual Emissions of Soil Carbon in the Project Area

Total Project Area (ha)	x	Rate of Soil Carbon Emissions (t C/ha-yr)	=	Annual Soil Carbon Emissions (t C/yr)

Formula 5.8 Estimate the Net Annual Emissions or Sequestration of Carbon in the Project Area

Annual Biomass Carbon Sequestration (t C/yr)	+	Annual Soil Carbon Accumulation (t C/yr)	+	Annual Biomass Carbon Emissions (t C/yr)	+	Annual Soil Carbon Emissions (t C/yr)	=	Net Annual Carbon Emissions (+) or Sequestration (-) (t C/yr)

Net Annual Carbon Emissions or Sequestration (t C/yr)	x	Molecular/Atomic Weight Ratio ($t\ CO_2/t\ C$)	=	Net Annual CO_2 Emissions (+) or Sequestration (-) ($t\ CO_2/yr$)

Formula 5.9 Estimate the Total Net Emissions or Sequestration of CO_2 in the Project Area

Y_f

; Net Annual CO_2 Emissions or Sequestration; where Y_i = initial project year, and Y_f = final project year

Y_i

- *Total Project Area:* The total project area is defined as the area over which the project impacts CO_2 fluxes. If a project area involves multiple land types and/or multiple activities, the project area should be divided into appropriate parcels and these formulas should be applied separately to each parcel.

- *Annual Biomass Growth Increment:* The annual biomass growth increment should include either aboveground biomass growth only, or both aboveground and belowground biomass growth, depending on data availability. If belowground biomass is excluded from the annual biomass growth increment, then it should also be excluded from the determination of the annual biomass harvested/destroyed (see below). Because CO_2 emissions are assigned a positive value, and carbon sequestration a negative value, the factor of (-1) is applied to carbon sequestered by biomass growth to maintain a consistent sign convention. As discussed in section 5.2.1, the annual biomass growth increment varies according to the species and age of the biomass as well as a broad range of climatic variables. If the precise timing of a project's GHG impacts is of interest to the Task Manager, then a variable biomass growth increment may need to be applied to more closely approximate the actual flux of CO_2 emissions and carbon sequestration on an annual basis. If the timing of a project's GHG impacts is less critical, then an average (linear) biomass growth increment may be applied.

- *Rate of Soil Carbon Accumulation/Emissions:* An increase in soil carbon stocks corresponds to carbon sequestration or CO_2 uptake; conversely, a decrease in soil carbon stocks corresponds to CO_2 emissions. Because CO_2 emissions are assigned a positive value, and carbon sequestration a negative value, the factor of (-1) is applied to soil carbon accumulation to maintain a consistent sign convention. If insufficient data are available regarding the annual rate of soil carbon accumulation or emissions in the project area, Formulas 5.5 and 5.7 need not be applied.

- *Biomass Carbon Content:* In the absence of site-specific data, a default value of 0.5 t C/t dm should be used.

- *Annual Biomass Harvested/Destroyed:* As discussed above, for the purpose of GHG impact accounting for most World Bank projects, it is assumed that 100 percent of the carbon contained in harvested or destroyed aboveground biomass is released to the atmosphere in the year of harvest. If no information is available on the fate of belowground biomass following the harvest or destruction of aboveground biomass, the Task Manager may choose to exclude belowground biomass from the total for biomass harvested/destroyed. In this case, belowground biomass should also be excluded from the determination of the annual biomass growth increment (see above).

- *Molecular/Atomic Weight Ratio:* To convert t C to t CO_2, apply the ratio of 44 t CO_2/12 t C.

- *Net CO_2 Emissions/Sequestration*: Because of the application of (-1) to Formulas 5.4 and 5.5, CO_2 emissions will be expressed as a positive value, and carbon sequestration as a negative value.

Case Studies 5-2 and 5-3 illustrate the application of the flow approach in order to measure the GHG benefits generated by a natural forest management project and a sustainable fuelwood woodlot project.

Case Study 5-2: Natural Forest Management Project

The World Bank proposes to fund a natural forest management project intended to regenerate 950 ha of degraded forest over a period of 15 years. The project activities consist of planting seedlings and conducting one sanitary thinning to promote the growth of desired tree species. These activities are anticipated to increase carbon stocks in above- and belowground biomass and soil. In the absence of the project, the biomass and soil carbon stocks on the degraded land are expected to remain constant. Because data are not available on the increase in belowground biomass and soil carbon stocks as a result of the project activities, these two carbon stocks are excluded from the calculation of the project's CO_2 benefits. Therefore, the estimate of project benefits will be conservative.

Under the project scenario, the project area contains 96 t dm/ha of aboveground biomass at the beginning of the project, and will accumulate new biomass at an average rate of 5 t dm/ha-yr for 15 years. (An average biomass growth rate is acceptable in this case because the timing of the project's CO_2 fluxes is not important to the Task Manager.) Zero CO_2 emissions occur in the first ten years of the project, and a thinning of 20 percent of the total stock will take place at the beginning of the eleventh year of the project. This thinning is equivalent to 29 t dm/ha-yr, based on the initial stock plus growth during the first ten years of the project. Zero CO_2 emissions occur in the last four years of the project. The carbon content of the biomass is estimated to be 0.5 t C/t dm.

To calculate annual flows of carbon emissions and sequestration under the project scenario, Formulas 5.4 through 5.9 (excluding Formulas 5.5 and 5.7 due to a lack of soil carbon data) are applied as follows:

For years 1-10 and 12-15:

Total Project Area	x	(Annual Biomass Growth Increment	x	Biomass Carbon Content)	x	(-1)	=	Annual Biomass Carbon Sequestration
950 ha		5 t dm/ha-yr		0.5 t C/t dm				-2,375 t C/yr

Annual Biomass Carbon Sequestration	+	Annual Biomass Carbon Emissions	=	Net Annual Biomass Carbon Sequestration
-2,375 t C/yr		0 t C/yr		-2,375 t C/yr

Net Annual Biomass Carbon Sequestration	x	Molecular/Atomic Weight Ratio	=	Net Annual CO_2 Sequestration
-2,375 t C/yr		44 t CO_2/12 t C		-8,708 t CO_2/yr

For year 11 only:

Total Project Area	x	(Annual Biomass Growth Increment	x	Biomass Carbon Content)	x	(-1)	=	Annual Biomass Carbon Sequestration
950 ha		5 t dm/ha-yr		0.5 t C/t dm				-2,375 t C/yr

Total Project Area	x	(Annual Biomass Harvested/Destroyed	x	Biomass Carbon Content)	=	Annual Biomass Carbon Emissions
950 ha		29 t dm/ha-yr		0.5 t C/t dm		13,775 t C/yr

Annual Biomass Carbon Sequestration	+	Annual Biomass Carbon Emissions	=	Net Annual Biomass Carbon Emissions
-2,375 t C/yr		13,775 t C/yr		11,400 t C/yr

Net Annual Biomass Carbon Emissions	x	Molecular/Atomic Weight Ratio	=	Net Annual CO_2 Emissions
11,400 t C/yr		44 t CO_2/12 t C		41,800 t CO_2/yr

Case Study 5-2: Natural Forest Management Project, cont.

For years 1-15:

Y_{15}
; Net Annual CO_2 Emissions or Sequestration
Y_1

= (-8,708 t CO_2/yr x 14 years) + (41,800 t CO_2/yr x 1 year)

= -80,112 t CO_2

Therefore, the project generates net sequestration equivalent to 80,112 t CO_2.

Case Study 5-3: Establishment of Fuelwood Woodlots

A World Bank project intends to establish 1,000 ha of woodlots on idle land to supply fuelwood to adjacent villages. The woodlots are assumed to accumulate aboveground biomass at an average annual rate of 15 t dm/ha-yr. A thinning of 10 percent of aboveground biomass stocks will occur at the end of year 5. This thinning will remove 7.5 t dm/ha of the aboveground biomass (= 15 t dm/ha-yr x 5 years x 0.10), based on the biomass increment during the first five years of the project. The project area will be harvested at the end of year 10, removing 142.5 t dm/ha of aboveground biomass (= {15 t dm/ha-yr x 10 years} - 7.5 t dm/ha removed by thinning in year 5). The Task Manager estimates that in the absence of the project, the idle land would remain unchanged, and an amount of fuelwood equivalent to the amount produced under the project scenario would be harvested from nearby woodlands, contributing to their degradation.

The proposed project activities impact not only the idle land area on which the woodlots will be established, but also the woodland area where deforestation will be avoided as a result of the project. Therefore, the accounting of CO_2 impacts of the project should include CO_2 emissions and carbon sequestration on both the idle land and the woodland. Due to a lack of data regarding the impacts of woodlot establishment and fuelwood harvesting on belowground biomass and soil carbon stocks, these two stocks will be excluded from the calculation of project benefits. Because belowground biomass and soil carbon stocks would be expected to increase as a result of project activities, the estimate of project benefits based on aboveground biomass stocks only will be conservative.

Under the project scenario, biomass growth will sequester carbon on the idle land for a period of 10 years. The thinning in year 5 and the harvest in year 10 will generate carbon emissions. To calculate annual flows of carbon emissions and sequestration under the project scenario, Formulas 5.4 through 5.9 (excluding Formulas 5.5 and 5.7 due to a lack of soil carbon data) are applied as follows:

For years 1-4 and 6-9:

Total Project Area	x	(Annual Biomass Growth Increment	x	Biomass Carbon Content)	x	(-1)	=	Annual Biomass Carbon Sequestration
1,000 ha		15 t dm/ha-yr		0.5 t C/t dm				-7,500 t C/yr

Annual Biomass Carbon Sequestration	+	Annual Biomass Carbon Emissions	=	Net Annual Biomass Carbon Sequestration
-7,500 t C/yr		0 t C/yr		-7,500 t C/yr

Net Annual Biomass Carbon Sequestration	x	Molecular/Atomic Weight Ratio	=	Net Annual CO_2 Sequestration
-7,500 t C/yr		44 t CO_2/12 t C		-27,500 t CO_2/yr

Case Study 5-3: Establishment of a Sustainable Fuelwood Woodlots, cont.

For year 5:

Total Project Area	x	(Annual Biomass Growth Increment	x	Biomass Carbon Content)	x (-1)		Annual Biomass Carbon Sequestration
1,000 ha		15 t dm/ha-yr		0.5 t C/t dm			-7,500 t C/yr

Total Project Area	x	(Annual Biomass Harvested/Destroyed	x	Biomass Carbon Content)	=	Annual Biomass Carbon Emissions
1,000 ha		.5 t dm/ha-yr		0.5 t C/t dm		3,750 t C/yr

Annual Biomass Carbon Sequestration	+	Annual Biomass Carbon Emissions	=	Net Annual Biomass Carbon Sequestration
-7,500 t C/yr		3,750 t C/yr		-3,750 t C/yr

Net Annual Biomass Carbon Sequestration	x	Molecular/Atomic Weight Ratio	=	Net Annual CO_2 Sequestration
-3,750 t C/yr		44 t CO_2/12 t C		-13,750 t CO_2/yr

For year 10:

Total Project Area	x	(Annual Biomass Growth Increment	x	Biomass Carbon Content)	x (-1)	=	Annual Biomass Carbon Sequestration
1,000 ha		15 t dm/ha-yr		0.5 t C/t dm			-7,500 t C/yr

Total Project Area	x	(Annual Biomass Harvested/Destroyed	x	Biomass Carbon Content)	=	Annual Biomass Carbon Emissions
1,000 ha		142.5 t dm/ha-yr		0.5 t C/t dm		71,250 t C/yr

Annual Biomass Carbon Sequestration	+	Annual Biomass Carbon Emissions	=	Net Annual Biomass Carbon Emissions
-7,500 t C/yr		71,250 t C/yr		63,750 t C/yr

Net Annual Biomass Carbon Emissions	x	Molecular/Atomic Weight Ratio	=	Net Annual CO_2 Emissions
63,750 t C/yr		44 t CO_2/12 t C		233,750 t CO_2/yr

Y_{10}
; Net Annual CO_2 Emissions or Sequestration, Project Scenario
Y_1

= (-27,500 t CO_2/yr x 8 years) + (-13,750 t CO_2/yr x 1 year) + (233,750 t C/yr x 1 year)

= 0 t CO_2

Under the reference scenario, the amount of fuelwood collected from the woodland is equal to the amount of fuelwood harvested under the project scenario. Since no carbon sequestration is assumed to occur in the woodland, the net carbon emissions under the reference scenario are equal to emissions from fuelwood harvesting under the project scenario, or 75,000 t C (= 3,750 t C + 71,250 t C). By applying the molecular/atomic weight ratio (44 t CO_2/t C), net CO_2 emissions under the reference scenario are determined to be 275,000 t CO_2.

Although the project does not generate CO_2 emissions or sequester carbon, it does produce a CO_2 benefit by preventing emissions of 275,000 t CO_2 that would have occurred under the reference case.

5.2.3 Estimation of Non-CO_2 Impacts of Open Biomass Burning

Several forestry activities involve open burning of biomass, or burning of vegetation in the field.[5] Burning is typically used as a land management tool, to clear lands of vegetation prior to planting crops or trees, or to enrich soils and regenerate certain plant species.

When vegetation is burned, most of the carbon contained in the biomass is either 1) oxidized and released to the atmosphere as CO_2, or 2) converted to charcoal, where it will remain stored indefinitely. Approximately 10 percent of the carbon in biomass that has been burned under open conditions is converted to charcoal. In addition to CO_2, open biomass burning generates emissions of other GHGs, including CH_4, N_2O, CO, NO_x, and NMVOCs.

World Bank Task Managers should account for both CO_2 and non-CO_2 emissions that are either produced by open biomass burning, or avoided due to the prevention of open biomass burning, as a result of project activities. Methods for estimating CO_2 emissions have already been provided in section 5.2.2 of this chapter. Methods for estimating CH_4, N_2O, CO, NO_x, are provided below; NMVOCs are not addressed further due to insufficient data on rates of emission.

The biomass burning calculations involve four steps:

- Step 1: Estimate the quantity of biomass burned.

The quantity of biomass burned is expressed in units of t dm. This quantity will usually be based on the aboveground biomass density of the site (t dm/ha), the project area (ha), and the fraction of biomass that is burned.

- Step 2: Estimate the total carbon released.

In step 2, the quantity of biomass burned (t dm) is multiplied by the fraction of biomass oxidized and the biomass carbon content (t C/t dm) to determine the total carbon released from burning (t C). The default value for the fraction of biomass oxidized is 0.9. (The fraction of burned biomass that is not oxidized remains on site as charcoal.)

- Step 3: Estimate the total nitrogen released.

To calculate the amount of nitrogen released (t N), the amount of carbon released from burning (t C) is multiplied by the ratio of nitrogen to carbon in the biomass. A default N/C ratio of 0.01 may be used (Crutzen and Andreae 1990).

- Step 4: Apply emission ratios and molecular/atomic weight ratios to determine total emissions of non-CO_2 GHGs.

Emission ratios for the carbon and nitrogen gases are then applied to the quantities of carbon and nitrogen released (t C and t N) to yield GHG emission estimates expressed in units of C or N, which then are converted to a full molecular weight basis.

Steps 2, 3, and 4 are implemented by applying Formulas 5.10, 5.11, and 5.12, in sequence, to the quantity of biomass burned. Default values for the emission ratios and molecular/atomic weight ratios (Step 4) are presented in Exhibit 5-12.

Formula 5.10 Estimate the Total Carbon Released from Biomass Burning

Total Project Area (ha)	x	Aboveground Biomass Density (t dm/ha)	x	Fraction of Biomass Burned	x	Fraction of Biomass Oxidized	x	Biomass Carbon Content (t C/t dm)	=	Total Carbon Released from Biomass Burning (t C)

Formula 5.11 Estimate the Total Nitrogen Released from Biomass Burning

Total Carbon Released from Biomass Burning (t C)	x	N/C Ratio (t N/t C)	=	Total Nitrogen Released from Biomass Burning (t N)

Formula 5.12 Estimate Non-CO2 Emissions from Biomass Burning

Carbon Released by Biomass Burning (t C)	x	Emission Ratio for CH_4	x	Molecular/Atomic Weight Ratio (t CH_4/t C)	=	CH_4 Emissions (t CH_4)
Carbon Released by Biomass Burning (t C)	x	Emission Ratio for CO	x	Molecular/Atomic Weight Ratio (t CO/t C)	=	CO Emissions (t CO)
Nitrogen Released by Biomass Burning (t N)	x	Emission Ratio for N_2O	x	Molecular/Atomic Weight Ratio (t N_2O/t N)	=	N_2O Emissions (t N_2O)
Nitrogen Released by Biomass Burning (t N)	x	Emission Ratio for NO_x	x	Molecular/Atomic Weight Ratio (t NO_x/t N)	=	NO_x Emissions (t NO_x)

EXHIBIT 5-12
EMISSION AND MOLECULAR/ATOMIC WEIGHT RATIOS FOR NON-CO_2 GHGS PRODUCED BY OPEN BIOMASS BURNING

Compound	Emission Ratios	Molecular/Atomic Weight Ratios
CH_4	0.012 (0.009 - 0.015)[a]	16/12
CO	0.06 (0.04 - 0.08)[b]	28/12
N_2O	0.007 (0.005 - 0.009)[c]	44/28
NO_x	0.121 (0.094 - 0.148)[c]	46/14

Source: UNEP/OECD/IEA/IPCC (1997), and references cited therein: [a]Delmas (1993), [b]Lacaux et al. (1993), and [c]Crutzen and Andreae (1990).
Note: Ratios for carbon compounds, i.e., CH4 and CO, are mass of carbon compound released (in units of C) relative to mass of total carbon released from burning. Those for nitrogen compounds are expressed as the ratios of emission (in units of N) relative to total nitrogen released from the fuel.

As discussed in chapter 2. Basic Principles, emissions of direct non-CO_2 GHGs (e.g., CH_4 and N_2O) can be expressed in terms of CO_2-equivalent emissions by applying the appropriate global warming potentials. However, emissions of indirect nor-CO_2 GHGs (e.g., CO and NO_x) cannot be expressed in terms of CO_2-equivalent emissions because the global warming potentials of these gases have not yet been determined.

5.3 Agriculture Projects

Agriculture projects can have both direct and indirect impacts on the absorption and emissions of GHGs. Four general categories of agriculture projects are identified in relation to their impacts on the absorption or emissions of GHGs. They are:

- **Productivity Improvements:** Agricultural productivity improvement projects have the objective of increasing unit agricultural production. As a result, the project may reduce the pressure on other land-use forms, particularly forests and thereby preserve an existing GHG sink. However, in some cases, the higher productivity may result in an increase in GHG emissions from the agricultural activities due to methane emission from higher yielding varieties (e.g., rice production) or higher use of energy and fertilizers. Estimating the net GHG impact of an agricultural productivity improvement project will require careful evaluation of both the positive and negative GHG impacts.

- **Soil Conservation:** Soil conservation projects have the objective of adjusting agricultural practices to reduce the loss and enhance the productivity of valuable top soils. As a result, these projects may increase the uptake or reduce the production of GHG's namely CH_4, N_2O and photochemically important compounds such as CO and No_x's. In many cases, soil conservation projects incorporate the use of specific tree species to stabilize soils, increase nitrogen fixation and improve soil fertility.

- **Soil Enhancement:** Soil enhancement projects have the specific objective of expanding specific tree species within the farming system to stabilize it, boost productivity and/or provide wood raw material or opportunities to expand the income base. This should also increase the store of carbon (and nitrogen) within the system. In some instances, this initiative can be viewed as a subset of the first set of agricultural projects;

- **Livestock Production:** Livestock production projects have the primary objective of either improving the productivity or increasing the production of the livestock sub-sector. The results of a livestock project can either increase or decrease the net GHG emission, primarily methane, depending on the objective of the project. If the objective of the project is to increase the productivity of the live-stock sub-sector, the result may be a net decrease in GHG emissions. However, if the project simply increases the production of livestock. The result may be an increase in GHG emissions.

An important category of agricultural improvement projects includes **rice production and methane reduction projects.** Increasing the area and intensity of rice crops under irrigation has also led to an increased emission of methane-- the most threatening carbon-based GHG in terms of the radiative or "forcing effect." Methods of estimating methane yield from rice production, (ruminant) domestic animals and decomposing biomass, particularly dung, are discussed by the IPCC (UNEP/OECD/IEA/IPCC 1995) together with options to reduce methane emissions or to use methane as an energy source.

5.3.1 Increasing Agricultural Productivity

From a GHG perspective the things that have to be accounted for are the direct and indirect increases or decreases in GHG sources and sinks. To understand and quantify the various "gains and losses," a simple example is given in Case Study 5-4. While this case study does not run through all the calculations, the information provided does assist an analyst in data collection and scenario definition.

Case Study 5-4: Agricultural Productivity Project

Under a World Bank Project, 1,200 ha of farm land is going to have an irrigation system installed. This will enable the farmer to produce 3 crops of rice per year in place of the one rainfed crop the farmers family normally produce. It is assumed that the output of rice per hectare per year will be 3 times what it is currently under a one crop regime. In measuring the emissions and storage of carbon, the following factors need to be taken into consideration:

1. Additional production of rice and rice straw
2. Additional production of CH_4 and other trace GHGs
3. Change in soil carbon level (if any) from continuous cropping of the land
4. Additional energy used for irrigation
5. Additional fertilizer and other energy intensive inputs
6. Any other relevant factors

Project Summary

Project Type:	Increasing Agricultural Production
Project Area:	1,200 hectares
Project Life:	5 years
Net GHG Impact (t CO_2):	135,185 t CO_2 will be added to the atmosphere
Production Gains:	24,000 t rice grain
	36,000 t straw and husks

Assumptions:

A. General

Soil Carbon Content (t C/ha)	100
Biomass Carbon Content Conversion Factor (t C/t biomass)	0.45
Energy Used to Produce and Distribute Fertilizer	
Nitrogen based (t diesel oil equivalent/t N)	0.80
Phosphorus based (t doe/t P)	0.20
Potassium based (t doe/t K)	0.20
Density of diesel oil (t diesel/1000 liter)	0.80
Carbon content of diesel oil (t C/t diesel)	0.84
CO_2 equivalent factors for methane	24.5

B. Reference Case

	unit/per hectare/yr
Annual Yield of Rice Grain	2,000 kg
Annual Yield of Rice Straw etc.	3,600 kg
Fertilizer Application N,P,K (per yer)	120 kg; 120 kg; 60 kg
Methane Emissions (per day)	2.3 kg CH_4
Growing Season (days)	114
Diesel Fuel for pumping (per year)	0 liter
Woody Biomass stock	0 t biomass

Case Study 5-4, cont.

C. Project Case

	unit /per hectare/yr
Annual Yield of Rice Grain	6,000 kg
Annual Yield of Rice Straw etc.	10,800 kg
Fertilizer Application N,P,K (per year)	360 kg; 360 kg; 180 kg
Methane Emissions (per day)	2.3 kg CH_4
Growing Season (days)	342
Diesel Fuel for pumping (per year)	3,600 liter
Woody Biomass stock	0 t biomass

D. Project Gains and Losses

- **i)** Because of the project, rice production will triple on the 1,200 ha, from 2,400 t per year to 7,200 t, thus there will be a net gain of 4,800 t of rice per year or 24,000 t over the five year project lifetime.
- **ii)** Similarly, the net gain in the straw and husk production will be 7,200 t/year or 36,000 t over the 5 year period. This additional straw etc. is of commercial value.
- **iii)** There is an additional input of fertilizers over the project's lifetime namely 1,400 t N, and 720 t K. This requires energy to manufacture and distribute; this energy is assumed to be from fossil fuels.
- **iv)** Methane emissions will increase by 629.28 t CH_4 per year or 3146.40 t CH_4 over the five year period.
- **v)** Consumption of diesel for pumping will increase by 3,456 t/year or 17,280 t for the five year period.
- **vi)** The carbon content of the soil remains constant over the five year project period at 100 t C per ha.

The six steps will only be applied to the gains or losses, except recording the initial and final store of carbon on the area.

Step 1: Measure the Woody Growing Stock and the Store of Carbon in Soil

(Growing Stock Initial Project Year t wood	x	Carbon Content Conversion Factor) 0.5 t C/t biomass	+	Soil Carbon Store t C	=	Total Store of Carbon in Growing Stock t C
(0	x	0.5)	+	120,000	=	**120,000 t C**

Step 2: Estimate the Annual Carbon Increment of the Resource

[Net Annual Biomass Growth t/yr		x	Carbon Conversion factor] t C/t biomass	+	Soil Carbon Increment t C	=	Annual Carbon Increment t C/yr
Rice	4,800	x	0.45	+	0	=	**5,400 t C/yr**
Straw	7,200	x	0.45				

Case Study 5-4, cont.

Step 3: For Each Year, Estimate Average Carbon Removed from the System; Additional Methane Production in CO_2 Equivalent Terms; and Additional Energy and Carbon Used for i) Fertilizer Production ii) Water Pumping, *again in CO_2 Equivalent Terms*

A. Additional Biomass

	Net Annual Removals t/yr	x	Carbon Conversion Factor t C/t biomass	=	Net Total Annual Removals t C/yr
Rice	4,800	x	0.45	=	**5,400 t C/yr**
Straw	7,200	x	0 45		

B. Additional Fertilizer: Energy Use

	Net Annual Increase in Consumption t of Chemical Element/yr	x	Fossil Fuel Required for Production and Transport t diesel equivalent	x	Carbon Content of diesel tC/td	x	CO2 Equivalent Conversion factor 44/12	=	Net annual CO_2 Equivalent t CO_2/yr
N	288	x	0 8						
P	288	x	0 2	x	0 84	x	3.667	=	**976 t CO_2/yr**
K	144	x	0.2						

C. Additional Pumping Water: Energy Use

Net Annual Increase in Diesel Consumption t of Diesel/yr	x	Carbon Content of Diesel tC/td	x	CO_2 Equivalent Conversion Factor 44/12	=	Net Annual CO_2 Equivalent t CO_2/yr
3,456	x	0 84	x	3.667	=	**10,644t CO_2/yr**

D. Additional Methane Production from Rice

Net Annual Methane Production t CH_4/yr	x	CO_2 Equivalent Factor	=	Total Net Annual Emission t CO_2/yr
		24.5		
629.28	x		=	**15,417 t CO_2/yr**

Step 4a: Estimate Annual Net Biomass Carbon Uptake or Release

Net Annual Carbon Increment t C	-	Net Annual Carbon Removals t C	=	Net Annual Increase in Store t C
5,400 t C	-	5,400 t C	=	**0 t C**

Case Study 5-4, cont.

Step 4b: Net Annual Carbon Dioxide Emissions

Annual Methane Equivalent $t\ CO_2/yr$	+	Fertilizer Equivalent $t\ CO_2/yr$	+	Pumping Equivalent $t\ CO_2/yr$	=	Total Annual CO_2 Emissions $t\ CO_2/yr$
15,417	+	976	+	10,644	=	**27,037 $t\ CO_2/yr$**

Step 5: Increase in Biomass and Soil Carbon Storage over Project's Lifetime

Carbon Storage Start of Project t C	+	[Annual Increment t C	x	Project Lifetime] years	=	Carbon Storage End of Project t C
120,000	+	[0	x	5]	=	**120,000 t C**

Step 6: Calculate the Net GHG Emissions over the Project Lifetime

Net Annual emissions $t\ CO_2$	x	Project Lifetime years	=	Total GHG Emissions $t\ CO_2$
27,037	x	5	=	**135,185 $t\ CO_2$**

5.3.2 Soil Conservation

5.3.2.1 Adjusting Agricultural Practices

By adjusting agricultural practices it is possible to enhance the uptake (and storage) of GHG's, and to lessen the emissions of GHG's while at the same time reduce the energy input into the system either directly or through the reduction of fertilizers, etc. In the book entitled *Soil Management and the Greenhouse Effect* (Lal et al. 1995), several ways of increasing the store of soil carbon on pastoral and arable agricultural lands are discussed. Amongst the measures that can be taken are:

- Ensuring the correct soil pH; many soils especially in the tropics are too acidic and inhibit the uptake of N, P, and K. By applying lime ($Ca\ (OH)_2$) or limestone ($Ca\ CO_3$) to the soil ensures that the inhibitor is neutralized and N, P and K can be absorbed by the plants;

- Applying drip irrigation or altering the irrigation regime to avoid waterlogging or saturation of the soil. For example, in Pakistan through poor irrigation management about 10 percent of the irrigated area is unusable for agriculture because of waterlogging or salinity;

- Improving the species or varieties of grain and grass crops with better carbon absorptive capacities;
- Adjusting the fertilizer applications to enhance production. This also includes the use of nitrogen fixing plants; and,

- Adjusting ground preparation techniques such as using "no-tillage" or conservation tillage practices.

- Terracing slopes to reduce erosion, thereby maintaining soil fertility and preventing further clearance of forest land. Case study 5-5 gives an example of soil conservation through terracing.

5.3.2.2 Reducing Methane Emissions

Methane production from agricultural systems, such as rice growing and animal production, has been increasing as the demand for grain and animal proteins has risen with increased population and rising income. While it is not feasible to reduce these expanding demands, it is possible to reduce the methane emissions by altering farming and livestock management practices.

The International Rice Research Institute (IRRI) in the Philippines has published several papers, such as *Methane Emissions from Rice Production*: (Neue 1995), which propose measures to reduce agricultural CH_4 emissions. Amongst the measures suggested are:

1) Adjusting the soil ph;
2) Lowering the water level in irrigated fields;
3) Adjusting the fertilizer practice; and
4) Improving the variety of rice.

These "best practices" should be made available to Bank project staff. Methods of measuring CH_4 production are also described in the publication by Neue. Regarding methane production from animals, the enteric production can be reduced by modifying diet, while methane production from dung can be adjusted (and collected) by altering practices.

Case Study 5-5: Soil Conservation Through Terracing

The project proposes to terrace 1,000 ha of newly felled woodland, which have been converted to agricultural crop land. From previous experience, the top soil will all be eroded in 5 years; the land will be abandoned and a new area of forest will be cleared. Over a period of 5 years, 1072 ha of forest would have to be cleared to maintain production of maize without terracing. The project initiatives include terracing the land and protecting the soil walls with trees and grasses. In addition, the farmers are taught improved farming practices. By terracing and protecting the soil walls, erosion is minimized and the crop land is protected for at least 100 years.

Although land area is taken up by the grasses and trees, there is no loss in grain production, because of improved agricultural practices, improved seed and mulching of tree leaves.

Case Study 5-5, cont.

Project Summary

Project Type:	Soil Conservation through Terracing
Project Area:	1,000 ha
Project Lifetime:	5 years
Carbon Sequestered on Project Area:	
CO_2 equivalent in wood:	9,717 t
CO_2 equivalent in grass:	693 t
CO_2 equivalent in soil:	3,666 t
Subtotal CO_2 equivalent:	14,076 t
Carbon Emission saved by not clearing 1,072 ha of forest:	
CO_2 equivalent in wood:	589,600 t
CO_2 equivalent in soil:	393,067 t
Subtotal CO_2 equivalent:	982,667 t
Total Sequestration and Emissions saved:	
CO_2 equivalent:	996,743 t
Production Increase over 5 years:	
Maize and straw:	unchanged
Wood:	2,100 t
Tree leaves (for mulching):	5,000 t
Grass:	270 t

Assumptions:

A. Reference Case

Year	1	2	3	4	5	Total
Maize production (kg/ha)	1000	800	600	400	200	3000
Straw etc (kg/ha)	1800	1444	1080	720	360	5400
Soil carbon content (t/ha)	100	80	60	40	20	300
New area of forest cleared to maintain maize production at 1000 t (1000 kg x 1000 ha) (ha)	0	200	240	288	344	1072

B. Proposed Project

Equivalent area under maize 870 ha, trees 100 ha, grass 30 ha; total 1000 ha.

Year	1	2	3	4	5	Total
Maize production (kg/ha)	1150	1150	1150	1150	1150	5750
Straw etc. (kg/ha)	2070	2070	2070	2070	2070	10,350
Tree growth per equivalent forest ha) t/ha (above and below ground)	2.0	5.5	9.5	14.0	22.0	53.0
Grass growth (per equivalent grass ha) (above and below ground)	2.0	3.0	3.0	3.0	3.0	14
Soil carbon accumulation (tC/ha)	100.2	100.4	100.6	100.8	101.0	101
Wood removals (t/tree ha)	1.0	2.0	4.0	6.0	8.0	21
Tree leaves (for mulching) (t/ha)	2.0	5.0	9.0	14.0	20.0	50
Grass removal (t/grass ha)	1.0	2.0	2.0	2.0	2.0	9

Case Study 5-5, cont.

The steps for estimation of the GHGs for any of these projects is similar to the above categories of projects.

Step 1: Measure the Woody Growing Stock and the Store of Carbon in Soil

(Growing Stock Initial Project Year t biomass	x	Carbon Content Conversion Factor) 0.5 tC/t biomass	+	Soil Carbon Store t C	=	Total Store of Carbon in Growing Stock t C
(0 t biomass	x	0.5)	+	100,000 t C	=	100,000 t C

Step 2: Estimate the Net Annual Carbon Increment of the Resource

(Average Annual Biomass Growth t biomass/yr		x	Carbon Content Conversion Factor) t C/t biomass	+	Annual Soil Carbon Increment t C/yr	=	Average Annual Carbon Increment t C/yr
Wood	1480		0.5				
Leaves	1000	x	0.45	+	200	=	1452
Grass	138		0.45				

Note: The gross average wood growth is the sum of each year's production and growth of wood divided by five. ie; (53 t/ha +21 t ha) x 100 ha/5 =1,480 t/yr of wood. For leaves it is 50 t x 100 ha/5=1000 t/yr.

Similarly, the gross average grass growth is the sum of each years production and growth of grass divided by five.

Step 3: Estimated the Average Annual Amount of Carbon Removed from the System.

(Average Annual Biomass Removed or Loss t C/yr		x	Carbon Content Conversion Factor) t C/t biomass	=	Total Annual Carbon Removal or Loss t C/yr
wood	420		0.50		
leaves	1,000	x	0.45	=	**684.3 t C/yr**
grass	54		0.45		

Note: The average removal from all biomass products, is their sum of removals divided by 5.

Step 4: Estimate the Net Annual Amount of Carbon Uptake or Release

Average Annual Carbon Increment t C/yr	-	Net Annual Carbon Uptake or Release t C/yr	=	Net Annual Store of Carbon t C /yr
1452	-	684	=	**768 t C/yr**

Case Study 5-5, cont.

Step 5: Calculate total Carbon Stored or Saved Over the Project's Lifetime

Step 5a: Increase in Biomass and Soil Carbon Storage Over the Projects Lifetime.

Carbon Storage Projects Start	+	**(Annual Increment**	x	**Project's Lifetime**	=	**Carbon Storage Project's End**
t C		t C		year		t C
100,000	+	(768	x	5)	=	**103,840**

Step 5b: Emission of GHG Saved Through not Clearing Forest Land

(Standing Forest Biomass	+	**Additional Soil Carbon Because of Trees**	x	**Area that would have been cleared**	=	**Total Carbon Saved in the Forest**
t C ha		t C ha		ha		t C
(150	+	100)	x	1072	=	**268,000**

Step 6: Calculate the net GHG Reduction Over the Project Life

Step 6a: Net GHG Stored Over the Project's Lifetime

Increase in Carbon Storage	x	**CO_2/C Conversion Factor**	=	**Increase in GHG storage**
t C		t CO_2/tC		t CO_2
(768 x 5)	x	44/12	=	**14,080**

Step 6b: Net GHG Saved by not Clearing Forest Land

Carbon Saved in Trees and Soil	x	**CO_2/C Conversion Factor**	=	**Total Saving of GHG Emissions**
t C		tCO_2/tC		t CO_2
268,000	x	44/12	=	**982,667**

Step 6c: Net GHG Stored and Saved Over the Projects Lifetime

GHG Stored	+	**GHG Saved**	=	**Total GHG Accumulated**
t CO_2		t CO_2		t CO_2
14,076	+	982,667	=	**996,763**

5.3.3 Soil Enhancement

The incorporation of trees in the agricultural system has been discussed in the forestry section and an agro-forestry case study, (Case Study 5-4) has been given. This project not only increases the fertilizer content of the soil, but through mulching, improves the soil structure. Therefore, soil enhancement techniques will not be described further here, other than note that a GHG assessment follows the same generic steps as in Section 5.3, where "C" (soil carbon) becomes a major factor in the equation.

5.4 Estimation of Methane Emissions from Livestock Management Projects

Livestock are a major source of methane emissions due to the release of methane from enteric fermentation (a product of ruminant digestion) and manure. As methane is a potent GHG, a project analyst should make first-order assessments of potential changes in methane emissions from a livestock project involving ruminants, especially dairy cows and cattle. Unlike the estimation process outlined previously for forestry and other agricultural projects, a project analysts follows different steps from those presented in Section 5.3 when estimating the net changes in methane emissions resulting from a proposed livestock management project.

Similar to all project-level GHG assessments, a project analyst is only worried about potential changes in GHG emissions over time when such changes are caused by human intervention. In the case of a proposed cattle and dairy cow project for example, if the project will change the feed mix and possible management practices of the herds then GHG estimation is warranted. Methane emission changes need to be estimated for potential changes during:

- Enteric fermentation; and
- Manure production.

Both reference and alternative cases must be defined by the project analyst, whereby the reference case equals the "without project" scenario, e.g., expected levels of methane emissions from the herds over the project life assuming the business as usual practices are followed. In contrast, the alternative scenario a situation where the Bank loan to the national dairy board allows for immediate introduction, and gradual adoption, in a province of feed that reduces the methane released during enteric fermentation and manure from the cows.

The emission factors for specific livestock types may be found in the IPCC guidelines, which gives default and regional values for dairy and non-dairy cattle. Note that an analyst must sum across types of affected livestock in the project, for example dairy and non-dairy cattle. Exhibit 5-13. provides enteric emissions factor information, showing typical default values from which first-order estimations can be made by an analyst. After summing across the cattle types for enteric emissions, next the analyst must estimate the emissions from manure production from these types of livestock. The equation for calculating emissions from manure production follows.

The steps involved in a GHG estimation of a livestock project are:

Step 1: Estimation of CH_4 Emissions from Enteric Fermentation by Livestock

Formula 5.13 Estimation of Total Annual Enteric Fermentation Emissions

Number of Livestock	x	**Annual Enteric Emissions Factor for Livestock**	x	**Unit Conversion**	=	**Total Annual Enteric Emissions**
head count		kg CH_4/head/yr	x	1t/1000 kg	=	t CH_4/yr

Step 2: Estimation of CH_4 Emissions from Manure Production by Livestock

Formula 5.14 Estimation of Total Annual Manure Emissions

Number of Livestock	x	Annual Manure Emissions Factor for Livestock	x	Unit Conversion	=	Total Annual Manure Emissions
head count		kg CH_4/head/yr		1 t/1000 kg		t CH_4/yr

Average values for manure production from differing cattle types by region and climatic conditions may be found in Exhibit 5-14. This information, again, is drawn from the IPCC inventory guidelines, and these values may be substituted for actual site or regional specific data if available. Finally for each cattle type, the total methane emissions for the project livestock is estimated by summing the enteric and manure-related emissions for each year. The calculation is:

Step 3: Total CH_4 Emissions from Livestock

Formula 5.15 Estimation of Total Annual Methane Emissions

Total Annual Enteric Emissions	+	Total Annual Manure Emissions	=	Total Annual Methane Emissions
t CH_4/yr		t CH_4/yr		t CH_4/yr

The above three steps are carried out for the reference and alternative project scenarios. To calculate the net changes in methane emissions over the project life between the reference and alternative project, an analyst makes the following estimation:

Step 4: Total Net Changes in CH_4 Emissions from the Livestock over the Project Life

Formula 5.16 Estimation of Total Net Methane Emissions

$\Sigma_{1\text{-}n}$ (Total Annual Methane Emissions of Reference Case)	-	$\Sigma_{1\text{-}n}$ (Total Annual Methane Emissions of Alternative Case)	=	Total Net Methane Emissions over Project Life
t CH_4		t CH_4		t CH_4

when:

n = project lifetime in years

By following the above set of steps, an initial estimation of GHG emissions for a project can be estimated (Case Study 5-6). If average annual emissions are expected to be constant over the project life, then the analyst need only multiply the number of project years by the value derived in Step 3 for each scenario. The analyst may convert these methane emissions into their CO_2 equivalents by multiplying by the global warming potential (the GWP for methane converted to CO_2 is 24.5 at present according to the IPCC guidelines), but most experts prefer to leave these values in terms of the actual GHG due to potential, and probable, changes in GWPs.

Exhibit 5-13: Average Enteric Fermentation Emission Factors for Cattle

Regional Characteristics	Animal Type	Emissions Factors (kg CH_4/head/yr)
North America	Dairy Cows	118
	Non-Dairy Cattle	47
Western Europe	Dairy Cows	100
	Non-Dairy Cattle	48
Eastern Europe	Dairy Cows	81
	Non-Dairy Cattle	56
Oceania	Dairy Cows	68
	Non-Dairy Cattle	53
Latin America	Dairy Cows	57
	Non-Dairy Cattle	49
Asia	Dairy Cows	56
	Non-Dairy Cattle	44
Africa and Middle East	Dairy Cows	36
	Non-Dairy Cattle	32
Indian Subcontinent	Dairy Cows	46
	Non-Dairy Cattle	25

Source: UNEP/OECD/IEA/IPCC (1995). Volume 3 page 4.11

Exhibit 5-14:
Manure Management Emissions Factors for Cattle, Swine, and Buffalo

Regional Characteristics	Animal Type	Emissions Factors by Climate Region[6] (kg/CH_4/head/year)		
		Cool	Temperature	Warm
North America	Dairy Cows	36	54	76
	Non-Dairy Cows	1	2	3
	Swine	10	14	18
Western Europe	Dairy Cows	14	44	81
	Non-Dairy Cows	6	20	38
	Swine	3	11	20
	Buffalo	3	8	17
Eastern Europe	Dairy Cows	6	19	33
	Non-Dairy Cows	4	13	23
	Swine	4	7	11
	Buffalo	3	9	16
Oceanica	Dairy Cows	31	32	33
	Non-Dairy Cows	5	6	7
	Swine	20	20	20
Latin America	Dairy Cows	0	1	2
	Non-Dairy Cows	1	2	1
	Swine	0	1	2
	Buffalo	1	1	2
Africa	Dairy Cows	1	1	1
	Non-Dairy Cows	0	1	1
	Swine	0	1	2
Middle East	Dairy Cows	1	2	2
	Non-Dairy Cows	1	1	1
	Swine	1	3	6
	Buffalo	4	5	5
Asia	Dairy Cows	7	16	27
	Non-Dairy Cows	1	1	2
	Swine	1	4	7
	Buffalo	1	2	3
Indian Subcontinent	Dairy Cows	5	5	6
	Non-Dairy Cows	2	2	2
	Swine	3	4	6
	Buffalo	4	5	5

A cool climate haves have an average temperature below 15°C; temperature climates have an average temperature between 15°C and 25°C; warm climates have an average temperature above 25°C. All climate categories are not Note: Significant buffalo populations do not exist in North America, Oceania, or Africa.

Source: UNEP/OECD/IEA/IPCC. 1995, Volume 3 page 4.13.

Case Study 5-6 Assessment of Livestock Methane Emissions of a Bank Project

The agricultural department of the World Bank is formulating a sectoral loan to an African country, part of which includes funds to provide to the National Dairy Association to on-lend to farmers money to purchase improved feedstock for their cattle, by raising the urea content of the cattle feed. The effect of this new feed is projected to decrease the enteric fermentation from an original estimate per head per year of dairy cattle from 36 CH_4/head/year to 30 CH_4/head/year and non-dairy cattle from 32 CH_4/head/year to 25 CH_4/head/year. Likewise the manure emissions factor from the cattle are projected to fall, with dairy and non-dairy cattle going from on average in the temperate zone of 1 kg CH_4/head/year to 0.75 CH_4/head/year. The Bank expects that this loan program can reach 100,000 head of cattle in the country, with a mix of 25% dairy to 75% non-dairy cattle. Any methane emission changes resulting from the project are projected to be constant over 10 years.

Project Summary	
Project Type:	Methane Reduction Project in Domestic Animals
Project Life:	10 years
Methane Saved over 10 years:	7,000 t CH_4
GHG Equivalency in CO_2 terms:	172,000 t CO_2 equivalent

Assumptions:

	Reference Case	**Proposed Bank Project**
Number of Dairy Cattle (head)	25,000	75,000
Number of Non-Dairy Cattle (head)	75,000	75,000
Enteric Emissions Factor		
Dairy Cattle (kg CH_4/head/year)	36	30
Non-Dairy Cattle (kg CH_4/head/year)	32	25
Manure Emission Factors		
Dairy Cattle (kg/CH_4/head/year)	1	0.75
Non-Dairy Cattle (kg/CH_4/head/year)	1	0.75
Project Life (years)	10	10

To estimate the projected net GHG emissions from the proposed project over the reference scenario, an analyst makes the following set of calculations:

A. Reference Scenario

Step 1: Estimation of CH_4 Emissions from Enteric Fermentation by Livestock of Reference Scenario

Formula 5.13 Estimation of Total Annual Enteric Fermentation Emissions

Dairy Cattle:

Number of Livestock head count 25,000	x	**Annual Enteric Emissions Factor for Livestock** kg CH_4/head/yr	x	1t/1000 kg	=	**Total Annual Enteric Emissions of Dairy Cattle** t CH_4/yr
25,000	x	36 kg CH_4/head year		1 t/1000 kg	=	**900 t CH_4/yr**

Case Study 5-6, cont.

Non-Dairy Cattle:

Number of Livestock	x	Annual Enteric Emissions Factor for Livestock	x	Unit Conversion	=	Total Annual Enteric Emissions of Dairy Cattle
herd count						
75,000		kg CH_4/head/yr				t CH_4/yr
75,000	x	32 kg CH_4/head/yr (1/1000)	x	1 t/1000 kg	=	**2,400 t CH_4/yr**

Step 2: Estimation of CH_4 Emissions from Manure Production by Livestock of Reference Scenario

Formula 5.14 Estimation of Total Annual Manure Emissions

Dairy and Non-Dairy Cattle

Manure production may be summed for the dairy and non-dairy cattle in this case study as the manure management emissions factor is the same for both types of ruminants.

Number of Livestock	x	Annual Manure Emissions Factor for Livestock	x	Unit Conversion		Total Annual Manure Emissions
head count		kg CH_4/head/yr		1 t/1000 kg		
100,000		1 kg CH_4/head/yr				t CH_4/yr
100,000	x	1 kg CH_4/head/yr x (1/1000)	x	(1/1000)	=	**100 t CH_4/yr**

Step 3: Total CH_4 Emissions from Livestock of Reference Scenario

Formula 5.15 Estimation of Total Annual Methane Emissions

Total Annual Enteric Emissions	+	Total Annual Manure Emissions	=	Total Annual Methane Emissions
t CH_4/yr		t CH_4/yr		t CH_4/yr
900+2,400	+	100	=	**3,400**

B. Proposed Project Scenario

Step 1: Estimation of CH_4 Emissions from Enteric Fermentation by Livestock of Proposed Project

Formula 5.16 Estimation of Total Annual Enteric Fermentation Emissions

Dairy Cattle:

Number of Livestock	x	Annual Enteric Emissions Factor for Livestock	=	Total Annual Enteric Emissions of Dairy Cattle
head count		kg CH_4/head/yr x 1000		t CH_4/yr
25,000	x	30 kg CH_4/head/yr x 1000	=	**750**

Case Study 5-6, cont.

Non-Dairy Cattle:

Number of Livestock herd count	x	Annual Enteric Emissions Factor for Livestock kg CH_4/head/yr	x	1 t/1000 kg	=	Total Annual Enteric Emissions of Dairy Cattle t CH_4/yr
75,000	x	25 kg CH_4/head/yr x 1/1000			=	**1,875 t CH_4/yr**

Step 2: Estimation of CH_4 Emissions from Manure Production by Livestock of Proposed Project

Formula 5.14 Estimation of Total Annual Manure Emissions

Dairy and Non-Dairy Cattle

Manure production may be summed for the dairy and non-dairy cattle in this case study as the manure management emissions factor is the same for both types of ruminants.

Number of Livestock head count	x	Annual Manure Emissions Factor for Livestock	=	Total Annual Manure Emissions
100,000		kg CH_4/head/yr x 1000		t CH_4/yr
100,000	x	0.75 kg CH_4/head/yr x 1/1000	=	**75 t CH_4/yr**

Step 3: Total CH_4 Emissions from Livestock of Proposed Project

Formula 5.15 Estimation of Total Annual Methane Emissions

Total Annual Enteric Emissions	+	Total Annual Manure Emissions	=	Total Annual Methane Emissions
t CH_4/yr		t CH_4/yr		t CH_4/yr
750 + 1,875	+	**75**	=	**2,700 t CH_4/yr**

The above three steps are carried out for the reference and alternative project scenarios. To calculate the net changes in methane emissions over the project life between the reference and alternative project, an analyst makes the following estimation:

Step 4: Total Net Changes in CH_4 Emissions from the Livestock Project over the Project Life

Formula 5.16 Estimation of Total Net Methane Emissions

(Total Annual Methane Emissions of Reference Case)	-	(Total Annual Methane Emissions of Alternative Case)	x	Project Years	=	Total Net Methane Emissions over Project Life
t CH_4/yr		t CH_4/yr		10 yrs		t CH_4
(3,400	-	2,700)	x	10	=	**7,000 t CH_4**

Thus, the project analysts expects that the introduction of improved feed among the cattle population in the region could result in approximately 7,000 t to methane emission savings. In CO_2 equivalent terms, this is equal to nearly **172,000** t of CO_2. (7,000t CH_4 x 24.5)

5.5 Other Land-Use Practices

There are several other land management activities that impact GHG fluxes, but do not fall within either the forest or agriculture category of activities. These activities, which are addressed in this section, include land flooding, wetland drainage, and other land-use conversions. However, because of the complex and uncertain nature of the GHG fluxes resulting from these activities, only partial methodologies for estimation of their GHG impacts are presented.

5.5.1 Flooding of Land

Flooding of land due to the construction of hydroelectric dams and reservoirs, construction or preservation of wetlands, or other land-use activities results in emissions of CH_4 generated by the anaerobic decomposition of (1) vegetation on the flooded land, (2) vegetation that regrows in the water, dies, and settles to the bottom, and (3) soil carbon. The CH_4 emissions from flooding vary according to the type and condition (i.e., biomass content) of the ecosystem that is flooded, as well as the depth and duration of flooding. Methane emissions from flooded lands are also strongly dependent on temperature, and therefore vary seasonally as well as daily. Flooding may also generate net emissions of N_2O and CO; however, these emissions are not accounted for at present because the flux of these gases resulting from flooding is highly uncertain.

Methane emissions from the flooding of land are calculated as the product of (1) the area of land to be flooded, (2) the number of days per year that the land is flooded, and (3) an average daily CH_4 emission rate (Formula 5.17). This rate, expressed in units of mg CH_4-C/m^2-day, varies according to land type, climate, and duration of flooding. Therefore, if a flooded project area involves multiple land types and/or variable periods of inundation, the project area should be subdivided into parcels with similar characteristics for the purpose of selecting appropriate CH_4 emission rates. Exhibit 5-15 lists average CH_4 emission rates and production periods (i.e., duration of flooding) for wetland categories ranging from bogs to lakes. Methane emission rates derived from local, regional, or national data should be substituted for these default values to the extent that such data are available.

Formula 5.17 Estimate Methane Emissions from Flooding of Land

Area of Flooded Land	x	Duration of Flooding	x	Average Daily CH_4 Emission Rate	x	Conversion Factor	x	Molecular/Atomic Weight Ratio	=	Annual CH_4 Emissions Produced
(m^2)		(days/yr)		(mg CH_4-C/m^2-day)		(t/mg)		(t CH_4/t CH_4-C)		(t CH_4/yr)

- *Average Daily CH_4 Emission Rate*: See Exhibit 5-15 for default values.
- *Conversion Factor*: The factor for converting milligrams to tonnes is 10^{-9} t/mg.
- *Molecular/Atomic Weight Ratio*: The molecular/atomic weight ratio for converting t CH_4-C to t CH_4 is 16 t CH_4/12 t CH_4-C.

EXHIBIT 5-15
AVERAGE METHANE EMISSIONS AND PRODUCTION PERIODS OF NATURAL WETLANDS

Wetland Categories ($mg\ CH_4/m^2.day$)	Emission Rate ($mg\ CH_4\text{-}C/m^2.day$)	Production Period or Length of Time Flooded (days)
Bogs	11 (1-38)	178
Fens	60 (21-162)	169
Swamps	63 (43-84)	274
Marshes	189 (103-299)	249
Floodplains	75 (37-150)	122
Lakes	32 (13-67)	365

Source: Source: UNEP/OECD/IEA/IPCC (1997), and references cited therein.

Note: These average daily emission rates from Aselmann and Crutzen (1989) are derived from measured emission rates in field experiments (the range in measured emission rates is in parentheses after the average), and average production periods are based on monthly mean temperature data and lengths of inundation.

5.5.2 Wetland Drainage

The World Bank may promote projects that entail the drainage or filling of wetlands. As discussed in section 5.5.1, freshwater wetlands and other flooded areas are a natural source of CH_4 emissions due to the anaerobic decomposition of organic material in wetland soils and water. Drainage or filling of wetlands reduces anaerobic decomposition of organic material and associated CH_4 emissions. These activities also increase the oxidation of organic material in the soil, thereby increasing CO_2 emissions. The magnitude of these effects is largely a function of the temperature and water content of the soil. In addition, the conversion of wetland soil to dryland soil could change the soil from a source to a sink of CH_4. Loss of wetlands area could also affect N_2O and CO fluxes; however, because both the direction and magnitude of these fluxes are highly uncertain, they are not included in GHG impact assessments at present.

The reduction in CH_4 emissions caused by draining wetlands is calculated as the product of (1) the area of drained land, (2) the number of days per year that the land was flooded prior to drainage, and (3) the difference between the average daily CH_4 emission rates before and after drainage (Formula 5-18). Default values for average daily CH_4 emission rates and flooding periods are listed in Exhibit 5-15. As mentioned above, CH_4 emission rates derived from local, regional, or national data should be substituted for these default values to the extent that such data are available.

Formula 5.18 Estimate Reduced Methane Emissions from Drainage of Wetlands

Area of Flooded Land Before Drainage (m^2) x Duration of Flooding Before Drainage (days/yr) x Difference Between Average Daily CH_4 Emission Rates ($mg\ CH_4\text{-}C/m^2\text{-}day$) x Conversion Factor (t/mg) x Molecular/Atomic Weight Ratio ($t\ CH_4/t\ CH_4\text{-}C$) = Annual CH_4 Emissions Reduced ($t\ CH_4/yr$)

- *Difference Between Average Daily CH_4 Emission Rates*: This is the difference between the average daily CH_4 emission rates before and after drainage. See Exhibit 5-15 for default values.
- *Conversion Factor*: The factor for converting milligrams to tonnes is 10^{-9} t/mg.
- *Molecular/Atomic Weight Ratio*: The molecular/atomic weight ratio for converting t CH_4-C to t CH_4 is 16 t CH_4/12 t CH_4-C.

5.5.3 Other Land-Use Conversions

Land-use conversions, such as from forest to agricultural land, natural grassland to managed pasture, or abandoned land to regenerated forest, not only cause CO_2 fluxes by altering biomass and soil carbon stocks, but also affect the natural flux of non-CO_2 GHGs between soils and the atmosphere. Soils act as a sink for atmospheric carbon and nitrogen, and land-use activities that alter the temperature, water content, or other characteristics of the soil have been documented to result in altered fluxes of N_2O and CH_4. For example, a study by Bowden and Bormann (1986) found that the clearcutting of temperate forests in the United States increased the flux of N_2O to the atmosphere via the degassing of N_2O dissolved in soil water. A study by Keller et al. (1986) found that net emissions of N_2O increased dramatically in newly cut tropical forests in Brazil and Ecuador, relative to undisturbed forest sites. The conversion of forest to agricultural land as well as from natural grassland to cultivated land has been found to decrease the capacity of soil to absorb atmospheric CH_4 (Keller et al. 1990, Scharffe et al. 1990). Soil disturbance due to land-use conversion may also generate CO emissions; however, this flux is not well understood at present.

Because little information is available on non-CO_2 soil fluxes due to land-use conversion, quantitative GHG estimation methods cannot yet be developed. However, Task Managers should still recognize that these fluxes may be significant in projects involving extensive land-use conversion, and, to the extent possible, describe these fluxes qualitatively.

Endnotes

[1] Carbon dioxide uptake refers the process by which growing vegetation absorbs atmospheric CO_2 through photosynthesis, and stores the carbon in its living tissue. It is also referred to as "carbon sequestration".

[2] Methods for estimating emissions from confined burning of vegetation and other organic material (i.e., biofuel combustion and charcoal manufacture) are described in chapter 3. Energy Project Assessment Methodology.

[3] The term "sink" is used loosely here. Strictly speaking, CO_2 does not have any sinks because it is never destroyed, but instead is continuously cycled among its reservoirs.

[4] Note: If open biomass burning is included in this list of activities, the Task Manager will also need to refer to section 5.2.3 for estimation methods for non-CO_2 emissions from biomass combustion.

[5] The word "open" is used here to distinguish field burning from burning in which useful energy is produced, i.e., "confined" burning. Confined burning of biomass is discussed in chapter 2. Energy Project Assessment Methodology.

[6] A cool climate have an average temperature below 15°C; temperature climates have an average temperature between 15°C and 25°C; warm climates have an average temperature above 25°C. All climate categories are not necessarily represented within every region. For example, there are no significant warm areas in Eastern or Western Europe. Similarly, there are no significant cool areas in Africa and the Middle East.

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ANNEX 1
PREFIXES, UNITS AND SYMBOLS

UNITS	Power of 10	Metric	Prefix
thousand	10^3	kilo	(k)
million	10^6	Mega	(M)
billion	10^9	Giga	(G)
trillion	10^{12}	Tera	(T)
quadrillion	10^{15}		

ENERGY SYMBOLS

	SI
J	joule,
Wh	watt- hour
	American General
cal, kcal	calorie, kilocalorie (10^3 cal)
Btu, BTU	British Thermal Unit
Q	Quadrillion Btu, or Quad (10^{15} Btu)
toe, TOE	Metric tons of crude oil equivalent (defined as 10 kcal--41.868 CJ in statistics employing net heating values)
tce, TCE	Metric tons of coal equivalent (defined as 0.7 x 10 kcal--29.31 GJ in statistics employing net heating values)
twe	Thousand tons of wood equivalent
boe, BOE	Barrels of (crude) oil equivalent (approx. 5.8 GJ)
bbl, BBL	Barrels of oil (crude or products) (equals 42 US gallons)

POWER (AND ELECTRICITY) SYMBOLS

	SI
W	Watt
v, V	Volt
a, A	Ampere
kVA	kilovolt-ampere
	American/General
BTU/hr	British Thermal Units per hour
hp	Horsepower
bd, b/d	Barrels of oil per day
bdoe	Barrels of oil equivalent per day (Barrels of daily oil equivalent)

WEIGHTS AND MEASURES

g, kg	Gram (or gramme), kilogram
lb, lbs	Pound, pounds
t, te, ton	Metric tonne, or 10^6 g (SI)
lt, ton	Long ton (Imperial; 2,240 pounds)
st, ton	Short ton (US; 2,000 pounds)
tpa, tpy	Tons per year
m, km	Meter, kilometer (SI)
mi	Miles
sq. m, m^2	Square meter
ha	Hectare (10^4 m^2)
ac	Acre
l	Liter, litre (SI)
cu. m, m^3	Cubic meter
gal	gallon (US or Imperial)
SCF, CF	Standard cubic foot (used for gases at normal temperature and pressure)

BIOMASS & OTHER

od, OD	Oven dry
odt, ODT	Oven dry ton
ad, AD	Air dry
CAI	Current annual increment
mcwb	Moisture content, wet basis
mcdb	Moisture content, dry basis
MAI	Mean Annual Increment
GHV, NHV	Gross and Net Heating Value

ANNEX 2
CONVERSION FACTORS

In all cases, multiply by the number in the appropriate cell of the table.
The second number is the power of 10 (e.g. +2 = 100, -3 = 10^{-3} or .001)

A few examples:

2 yd = 2 x 4.9374 x 10^{-4} international nautical miles
1 acre = 4.0469 x 10^{3} square meters
3 miles^2 = 3 x 4.0145 x 10^{9} square inch.

LENGTH

To convert--- > into	m		ft		yd		mile		International NM	
		Power of 10		Power of 10		Power of 10		Power of 10		Power of 10
meter	1		3.0480:	-1	9.1440:	-1	1.6093:	3	1.8520:	3
foot	3.2808:	0	1		3.0000:	0	5.2800:	3	6,0761:	3
yard	1.0936:	0	33333:	-1	1		1.7600:	3	2,0254:	3
statute mile	6.2137:	-4	1,8939:	-4	5,6818:	-1	1		1.1508:	0
international nautical mile	5.3996:	-4	1,6458:	-4	4.9374:	-4	8.6898:	-1	1	

AREA

To convert --- > into	m2		in2		ft2		yd2		acre		mile2	
		Power of 10		Power of 10		Power of 10		Power of 10		Power of 10		Power of 10
square meter	1		6.4516	-4	9.2903:	-2	8.3613:	-1	4.0469:	3	2.59	6
square inch	1.5500:	3	1		1.4400:	2	1.296	3	6.2726	6	4.0145:	9
square foot	1.0764:	1	6.9444	-3	1		9	0	4.356	4	2.7878:	7
square yard	1.196	0	7.716	-4	1.1111	-1	1		4.84	3	3.0976:	6
acre	2.4711:	-4	1.5942	-7	2.2957	-5	2.0661:	-4	1		6.4000:	2
square mile	3,8610:	-7	2.491	-10	3.587	-8	3.2283	-7	1.5625	-3	1	

VOLUME

To convert —> into	m3		l		ft3		yd3		UK fl oz		UK Pint		UK gal		US fl oz		US Pt		US gal	
		Power of 10		Power of 10		Power of 10		Power of 10		Power of 10		Power of 10		Power of 10		Power of 10		Power of 10		Power of 10
cubic metre	1		1.0000:	-3	2.8317:	-2	7.6455:	-1	2.8413:	-5	5.6826:	-4	4.5461:	-3	2.9574:	-5	4.7318:	-4	3.7854:	-3
litre	9.9997	-2	1		2.8316:	-1	7.6453:	2	2.8412:	-2	5.6825:	-1	4.5460:	0	2.9573:	-2	4.7316:	-1	3.7853:	0
cubic foot	3.5315	0.1	3.5316:	-2	1		2.7000:	1	1.0034:	-3	2.0068:	-2	1.6054:	-1	1.0444:	-3	1.6710:	-2	1.3368:	-1
cubic yard	1.308	0	1.3080:	-3	3.7037:	-2	1		3.7163:	-5	7.4326:	-4	5.9461:	-3	3.8681:	-5	6.1889:	-4	4.9511:	-3
UK fluid ounce	3.5195	4	3.5196:	1	9.9661:	2	2.6909:	4	1		2.0000:	1	1.6000:	2	1.0408:	0	1.6653:	-1	1.3323:	2
UK pint	1.7598	-3	1.7598:	0	4.9831:	1	1.3454:	-3	5.0000:	-2	1		8.0000:	0	5.2042:	-2	8.3267;	-1	6.6614:	0
UK gallon	2.1997	2	2.1998:	-1	6.2288:	0	1.6818:	2	6.2500:	-3	1.2500:	-1	1		6.5053:	-3	1.0408:	0	8.3267:	-1
US fluid ounce	3.3814	4	3.3815:	1	9.5751:	2	2.5853:	4	9.6076:	-1	1.9215:	1	1.5372:	2	1		1.6000:	1	1.2800:	-2
US pint	2.1134	3	2.1134:	0	5.9844:	1	1.6158:	3	6.0047:	-2	1.2009:	0	9.6076:	0	6.2500:	-2	1		8.0000:	0
US gallon	2.6417	2	2.6418:	-1	7.4805:	0	2.Oi97:	2	7.5059:	-3	1.5012:	-1	1.2009:	0	7.8125:	-3	1.2500:	-1	1	

MASS

To convert —> into	kg		t		lb		UK ton		sh ton	
		Power of 10		Power of 10		Power of 10		Power of 10		Power of 10
kilogram	1		1.0000:	3	4.5359:	-1	1.0160:	3	9.0718:	2
tonne	1.0000:	-3	1		4.5359	-4	1.0160:	0	9.0718	-1
pound	2.2046:	0	2.2046:	3	1		2.2400:	3	2.0000:	3
UK ton (=long ton)	9.8421:	-4	9.8421:	-1	4.4643:	-4	1		8.9286:	-1
short ton	1.1023:	-3	1.1023:	0	5.0000:	-4	1.1200:	0	1	

ANNEX 3
DIRECT GLOBAL WARMING POTENTIALS (GWP) OF GASES

Species	Chemical Formula	Atmospheric Lifetime	Direct Effect for Time Horizons of:		
			20 years	100 years	500 years
Carbon dioxide	CO_2	(a)	1	1	1
Methane (b)	CH_4	12.2+/- 3 (c)	56	21	6.5
Nitrous Oxide	N_2O	120	280	310	170
CFC-11	$CFCl_3$	50+/-5	5,000	4,000	1,400
CFC-12	CF_2Cl_2	102	7,900	8,500	4,200
HCFC-22	CF_2HCl	13.3	4,300	1,700	520
HFC-134	CHF_2CHF_2	11.9	3,100	1,200	370
HFC-152a	$C_2H_4F_2$	1.5	460	140	44
Carbon Monoxide	CO	months	-	-	-
Non-Methane Hydrocarbons	NMHCs	days to months	-	-	-
Nitrogen Oxides	NO_x	years	-	-	-

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 and WMO 1994.) This exhibit was taken from *Guidelines for Climate Change Global Overlays* (World Bank 1997b) and updated to reflect IPCC 1996.

(a) decay of CO_2 is a complex function of the carbon cycle.

(b) Includes 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.

(c) Represents adjustment time rather than atmospheric lifetime.

ANNEX 4
1990 COUNTRY-SPECIFIC NET CALORIFIC VALUES

Countries (Terajoule per kilotonne)

	Australia	Austria	Belgium	Canada	Denmark	Finland	France	Germany	Greece	Iceland	Ireland	Italy
OIL												
Crude Oil	43.21	42.75	42.75	42.79	42.71	42.66	42.75	42.75	42.75		42.83	42.75
NGL	45.22	45.22		45.22			45.22		45.22			45.22
Refinery Feedst.	42.50	42.50	42.50	42.5	42.5	42.5	42.5	42.5	42.5		42.5	42.5
COAL												
Coking Coal												
Production	28.34			28.78			28.91	28.96				
Imports		28.00	29.31	27.55		34.33	30.5	28.96		27.44	29.1	30.97
Exports	28.21			28.78				28.96				
Other Bituminous Coal and Anthracite*												
Production	24.39		25.00	28.78		26.71	24.96				26.13	26.16
Imports		28.00	25.00	27.55	26.09	26.38	25.52	26.52	27.21	25.85	29.98	26.16
Exports	25.65		25.00	28.78	26.09		26.43	31.71			26.13	
Sub-Bituminous Coal												
Production	17.87		18.06	17.38								
Imports												
Exports			18.2									
Lignite												
Production	9.31	10.9		14.25			17.94	8.41	5.74			10.47
Imports	10.9	21.56				17.94	14.88			19.82	10.47	
Exports		10.9		14.25				8.4				
Coal Products												
Patent Fuel/BKB	21.00	19.3	23.81		18.27		28.8	20.64	15.28		20.98	
Coke	25.65	28.2	29.31	27.39	31.84	28.89	28.71	28.65	29.3	26.65	32.66	29.3

	Japan	Luxembourg	Netherlands	NZ	Norway	Portugal	Spain	Sweden	Switzerland	Turkey	UK	USA
OIL												
Crude Oil	42.62		42.71	43.12	42.96	42.71	42.66	42.75	42.96	42.79	42.83	42.71
NGL	46.05		45.22	46.05	45.22		45.22				46.89	45.22
Refinery Feedst.	42.5		42.5	44.8	42.5	42.5	42.5	42.5	42.5	42.5	42.5	42.5
COAL												
Coking Coal												
Production	30.63			28.00		29.16				33.49	29.27	29.68
Imports	30.23		29.3	28.00		29.3	30.14	30.00		33.49	30.07	
Exports				28.00							29.27	29.68
Other Bituminous Coal and Anthracite*												
Production	23.07		26.00	28.1		21.07	14.24			29.3	24.11	26.66
Imports	24.66	29.3		28.1	26.59	25.54	26.98	28.05		27.21	26.31	27.69
Exports		29.3		28.1		23.00	26.98	28.05			27.53	28.09
Sub-Bituminous Coal												
Production				21.3		17.16	11.35					19.43
Imports							11.35					
Exports												
Lignite												
Production				14.1			7.84			9.63		14.19
Imports		20.03	20.00					8.37		12.56		
Exports			20.00									
Coal Products												
Patent Fuel/BKB	27.05	20.1	23.53				20.31	20.1	21.76	20.93	26.26	
Coke	28.64	28.5	28.5		28.5	28.05	30.14	28.05	28.05	29.28	26.54	27.47

Non-Annex 1 Countries (Terajoule per kilotonne)

	Albania	Algeria	Angola Cabinda	Argentina	Armenia	Azerbaijan	Bahrain	Bangladesh	Belarus	Benin	Bolivia
OIL											
Crude Oil	41.45	43.29	42.75	42.29		42.08	42.71	42.16	42.08	42.58	43.33
NGL		43.29		42.5			42.71	42.71			43.33
COAL											
Hard Coal											
Production		25.75		24.7							
Imports	27.21	25.75		30.14	18.58	18.58		20.93	25.54		
Exports				24.7	18.58	18.58			25.54		
Lignite and Sub-Bituminous Coal											
Production	9.84										
Imports	-			14.65	14.65	14.65					
Exports	9.84			14.65	14.65	14.65					
Coal Products											
Patent Fuel/BKB	-			29.31	29.31	29.31					
Coke	27.21	27.21	28.46	25.12	25.12	25.12					

	Brazil	Brunei	Bulgaria	Cameroon	Chile	China	Colombia	Congo	Cuba	Cyprus	Czech Republic
OIL											
Crude Oil	42.54	42.75	42.62	42.45	42.91	42.62	42.24	42.91	41.16	42.48	41.78
NGL	45.22	42.75			42.87		41.87				
COAL											
Hard Coal											
Production	18.42		24.7		28.43	20.52	27.21				24.4
Imports	30.56		24.7		28.43	20.52			25.75	25.75	23.92
Exports						20.52	27.21				27.98
Lignite and Sub-Bituminous Coal											
Production			7.03		17.17						12.26
Imports											
Exports											15.26
Coal Products											
Patent Fuel/BKB			20.1					21.28			
Coke	28.3		27.21		28.43	28.47	20.1		27.21		27.01

	Ecuador	Egypt	Estonia	Ethiopia	Gabon	Georgia	Ghana	Guatemala	Hong Kong	Hungary	India
OIL											
Crude Oil	42.45	42.54		42.62	42.62	42.08	42.62	42.45		40.36	42.79
NGL	42.45	42.54								45.18	43.00
COAL											
Hard Coal											
Production					18.58				16.42	19.98	
Imports		18.58			18.58	25.75		25.75	26.33	25.75	
Exports		18.58			18.58				24.15	19.98	
Lignite and Sub-Bituminous Coal											
Production			14.65							10.55	9.8
Imports			14.65			14.65				9.91	
Exports			14.65			14.65					
Coal Products											
Patent Fuel/BKB			20.1			29.31				21.44	20.1
Coke		27.21	25.12			25.12			27.21	30.11	

	Indonesia	Iran	Iraq	Israel	Ivory Coast	Jamaica	Jordan	Kazakhstan	Kenya	Kuwait	Kyrgyztan	
OIL												
Crude Oil	42.66	42.66	42.83	42.54	42.62	42.16	42.58	42.08	42.08	42.54	42.08	
NGL	42.77	42.54	42.83							42.62		
COAL												
Hard Coal												
Production	25.75	25.75						18.58			18.58	
Imports	25.75	25.75		26.63		25.75		18.58	25.75		18.58	
Exports	25.75							18.58			18.58	
Lignite and Sub-Bituminous Coal												
Production									14.65			14.65
Imports									14.65			14.65
Exports									14.65			14.65
Coal Products												
Patent Fuel/BKB									29.31			29.31
Coke	27.21							25.12			25.12	

	Latvia	Lebanon	Libya	Lithuania	Malaysia	Malta	Mexico	Moldova	Morocco	Mozambique	Myanmar
OIL											
Crude Oil		42.16	43.00	42.08	42.71		42.35		43.00		42.24
NGL					43.12		46.81				42.71
COAL											
Hard Coal											
Production					25.75		24.72		23.45	25.8	25.75
Imports	18.6			18.59	25.75	25.8	30.18	18.58	27.63	25.8	25.75
Exports	18.6			18.59	25.75		22.41	18.58			
Lignite and Sub-Bituminous Coal											
Production											8.37
Imports	14.7			14.65				14.65			
Exports	14.7			14.65				14.65			
Coal Products											
Patent Fuel/BKB	29.3			29.31				29.31			
Coke	25.1			25.12	27.21		27.96	25.12	27.21		27.21

	Nepal	Neth. Antilles	Neutral Zone	Nigeria	North Korea	Oman	Pakistan	Panama	Paraguay	Peru	Philippines
OIL											
Crude Oil		42.16	42.1	42.75	42.16	42.7	42.87	42.16	42.54	42.8	42.58
NGL										42.8	
COAL											
Hard Coal											
Production				25.75	25.75		18.73			29.3	20.1
Imports	25.1				25.75		27.54			29.3	20.52
Exports				25.75	25.75						
Lignite and Sub-Bituminous Coal											
Production					17.58						8.37
Imports										-	
Exports											
Coal Products											
Patent Fuel/BKB											
Coke				27.21	27.21						
										27.2	27.21

	Poland	Qatar	Romania	Russia	Saudi Arabia	Senegal	Singapore	South Africa	South Korea	Slovak Republic	Sri Lanka
OIL											
Crude Oil	41.27	42.87	40.65	42.08	42.54	42.62	42.71	44.13	42.71	41.78	42.16
NGL		43.00			42.62						
COAL											
Hard Coal											
Production	22.95		16.33	18.58				25.09	19.26		
Imports	29.41		25.12	18.58					27.21	23.92	25.75
Exports	25.09			18.58				25.09			
Lignite and Sub-Bituminous Coal											
Production	8.36										
Imports		7.24	14.65							12.26	
Exports	9.00	7.24	14.65								
Coal Products			14.65							15.26	
Patent Fuel/BKB	20.93		14.65	29.31						21.28	
Coke	27.76		20.81	25.12			27.21			27.01	

	Sudan	Syria	Taiwan	Tajikistan	Tanzania	Thailand	Trinidad/ Tobago	Tunisia	Turkmenistan	Ukraine	United Arab Emirates
OIL											
Crude Oil	42.62	42.04	41.41	42.08	42.62	42.62	42.24	43.12	42.08	42.08	42.62
NGL						46.85		43.12			
COAL											
Hard Coal											
Production			25.96	18.58	25.75					21.59	
Imports			27.42	18.58		26.38		25.75	18.58	25.54	
Exports				18.58					18.58	21.59	
Lignite and Sub-Bituminous Coal											
Production						12.14				14.65	
Imports									14.65	14.65	
Exports				14.65					14.65	14.65	
Coal Products				14.65							
Patent Fuel/BKB				29.31							
Coke				25.12	27.21	27.21		27.21	25.12	25.12	

		Uruguay	Uzbekistan	Venezuela	Vietnam	Yemen	Former Yugoslavia	Zaire	Zambia	Zimbabwe
OIL										
Crude Oil		42.71	42.08	42.06	42.61	43.00	42.75	42.16	42.16	
NGL				41.99						
COAL										
Hard Coal										
Production			18.58	25.75	20.91		23.55	24.71	25.75	
Imports			18.58				30.69		25.75	
Exports			18.58	25.75	20.91			24.71	25.75	
Lignite and Sub-Bituminous Coal										
Production							8.89			
Imports			14.65				16.91			
Exports			14.65				16.9			
Coal Products										
Patent Fuel/BKB			29.31				20.1	29.31		
Coke			25.12	27.21	27.21		26.9	27.21		27.21

Source: OECD/IEA, 1993, as presented in IPCC, 1995.
The conversion factors are those used by the IEA in the construction of energy balances.
Crude oil conversion factors are based on weighted average production data.

ANNEX 5
TYPICAL ENERGY CONTENT OF FOSSIL AND BIOMASS FUELS

Solid Fuels	**Density**	**Moisture Content Wet Basis** (% mcwb)	**Typical Net Heating Values a/** (MJ/kg)
Biomass Fuels			
Wood (wet, freshing cut)		40	10.9
Wood (air-dry, humid zone)		20	15.5
Wood (air-dry, dry zone)		15	6.6
Wood (oven-dry)		0	20.0
Charcoal		5	29.0
Bagasse (wet)		50	8.2
Bagasse (air-dry)		9	14.4
Coffee husks		12	16.0
Ricehulls (air-dry)		9	14.4
Wheat straw		12	15.2
Maize (stalk)		12	14.7
Maize (cobs)		11	15.4
Cotton gin trash		24	11.9
Cotton stalk		12	16.4
Coconut husks		40	9.8
Coconut Shells		13	17.9
Dung Cakes (dried)		12	12.0
Fossil-Fuels			
Anthracite	1.4-1.8	5	31.4
Bituminous coal	1.2-1.5	5	29.3
Sub-bituminous coal		5	18.8
Lignite	1.1-1.4	-	11.3
Peat (turf/dry)	0.65-0.85	-	29.3
Lignite briquettes		-	20.1
Coke briquettes		-	23.9
Peat briquettes		-	21.8
Coke (from coal)	1.0-1.4	-	28.5
Petroleum coke		-	35.2

Liquid Fuels	Specifc	Net Heating Values	
		Gravity*	(MJ/kg)
(MJ/litre)			
Fossil Fuels			
Crude Oil	0.86	41.9	36.7
LPG	0.54	45.6	24.6
Propane	0.51	45.7	23.3
Butane	0.58	45.3	26.3
Gasoline	0.74	43.9	32.6
Avgas	0.71	44.3	31.5
Motor gasoline	0.74	44.0	32.6
Wide-cut	0.76	43.7	33.3
White spirit	0.78	43.5	34.0
Kerosene	0.81	43.2	35.0
Aviation turbine fuel	0.82	43.1	35.4
Distillate fuel oil			
Heating oil	0.83	43.0	35.7
Autodiesel	0.84	42.8	36.0
Heavy diesel	0.88	42.4	37.3
Residual fuel oil	0.94	41.5	39.0
Light	0.93	41.8	38.9
Heavy	0.96	41.4	39.8
Lubricating oils	0.881	42.4	37.3
Asphalt	1.05	37.0	38.9
Tar	1.20	38.5	46.3
Liquified natural gas	0.42	52.8	22.2
Biomass-Derived liquids			
Ethanol	0.79	27.6	21.9
Methanol	0.80	20.9	16.8

* Note: Specific gravity is equivalent to density. The specific gravity is the weight relative to water, where 1 m^3 of water = t tonne.

Gas	Density (kg/m³)	Net Heating Values (MJ/m³)
Fossil Fuels		
Natural Gas	0.74	34.8
Refinery Gas	0.95	46.1
Methane	0.72	33.5
Ethane	1.36	59.5
Propane (LPG)	2.02	85.8
Butane (LPG)	2.67	111.8
Pentane	3.22	134.0
Coke oven gas	0.44	16.6 - 24.0
Town gas	0.53	16.7
Biomass-Derived		
Producer gas	1.13	5.9
Digester or Biogas	1.14	22.5
		(MJ/kWh)
Electricity	NA	3.6

a Based on given moisture contents

Note: For biomass fuels, these data should be used only as rough approximations.

Sources: Leach and Gowen. 1985. Biomass fuels--various (see text) modern/non-traditional fuels--FEA (1977).

ANNEX 6
EMISSIONS FACTORS FOR UTILITY AND INDUSTRIAL COMBUSTION SYSTEMS

	Emissions Factors (g/GJ energy input)				
Source	**CO_2**	**CO**	**CH_4**	**NOx**	**N_2O**
Utility Applications					
Natural gas boilers	56,100	19	0.1	267	n/a
Gas turbine, combined cycle,	56,100	32	6.1	187	n/a
Gas turbine, simple cycle	56,100	32	5.9	188	n/a
Residual oil boilers	77,350	15	0.7	201	n/a
Distillate oil boilers	74,050	15	0.03	69	n/a
Municipal solid waste (mass feed)	n/a	98	n/a	140	n/a
Coal, spreader stoker	94,600	121	0.7	326	0.8
Coal, fluidized bed	94,600	n/a	0.6	255	n/a
Coal, pulverized	94,600	14	0.6	857	0.8
Coal, tangentially fired	94,600	14	0.6	330	0.8
Coal, pulverized, wall fired	94,600	14	0.6	461	0.8
Wood-fired boilers	26,260*	147	0.8	112	n/a
Industrial Applications					
Coal-fired boilers	94,600	93	2.4	329	n/a
Residual-fired boilers	77,350	15	2.9	161	n/a
Natural gas-fired boilers	56,100	17	1.4	67	n/a
Wood-fired boilers	26,260*	150	0.5	115	n/a
Bagasse/agricultural waste boilers	n/a	170	n/a	88	n/a
Municipal solid waste, mass burn	n/a	96	n/a	140	n/a
Municipal solid waste, small modular	n/a	19	n/a	139	n/a

Source: IPCC/OECD/IEA/UNEP, 1991.

Notes: values are based on lower heating value, converted from original data in higher heating value using OECD/IEA assumptions (lower heating value is 10% below the higher heating value for natural gas; 5% for coal and oil); CO_2 values for coal represent an average value of sub-bituminous through anthracite; n/a is not available.

*Values for wood fired boilers derived seperately; not reported in IPCC/OECD/IEA/UNEP 1995.

ANNEX 7
GHG EMISSIONS FROM DEMAND SIDE MANAGEMENT PROJECTS

A.7-1 Introduction

Demand side management (DSM) projects are designed to reduce energy consumption at consumer level while maintaining the same level of energy services as prior to project implementation. There are two types of DSM projects:

Energy Efficiency: focuses on modifications in technology such as improvements in lighting, climate control, and motors.

Energy Conservation: focuses on changing energy consumption use patterns through educational projects and the use of time of day tariffs. For example, during peak periods, utilities often must rely on oil- or coal-fired power plants to provide electricity. If major industries reduce or eliminate energy intensive processes during morning and evening peak periods, they can reduce the need to add costly and GHG emitting capacity.

Many DSM projects involve a combination of energy efficiency and conservation measures that typically result in low and no cost options for various consumer groups - industries, commercial buildings, and households.

A.7-2 Methodology for Determining GHG Emissions from DSM Projects

The following sections outline the methodology for measuring changes in GHG emissions resulting from the implementation of DSM projects in the following economic sectors:

- industrial,
- residential and commercial, and
- transport.

The methodology for calculating GHG emissions from DSM projects is outlined below:

- Define the DSM Objective: Develop the Reference and Project Scenarios
- Gather and Analyze Data: Gather and analyze data. If necessary, create statistical samples.
- Calculate Energy Consumption GHG Emissions for Project and Reference Scenarios

Exhibit A.6-4 lists the DSM applications by sector

A.7-3 Methodology for determining GHG Emissions

Defining the Objective: Developing the Project and Reference Scenarios

The objective of GHG emissions evaluation is to define reference and project scenarios and then determine the net difference in GHG emissions between the two scenarios. This relationship is represented by the following equation:

$$\text{Emissions Impact} = \text{Emissions}_{ref} - \text{Emissions}_{proj}$$

where,

Emissions Impact = impact on GHG emissions due to the existence of the project.

Emissions_{ref} = an estimation of emissions assuming that no DSM project was implemented. This includes any changes in energy use not related to the project that may impact on GHG emissions.

Emissions_{proj} = measures total GHG emissions following DSM project implementation.

There are several factors that can either improve or hinder the project's outcome and must be addressed in any evaluation of the data used in building the project scenario.[1]

Self-selection bias - very common in DSM projects, this occurs when participants select themselves into the project. Participants should be chosen at random. One manifestation of self-selection bias is that the participants may believe in DSM and be more willing to work toward the project's success than the general population.

Free-riders - refers to project participants who would have undertaken project objectives even in the absence of the project. This factor skews the analysis to present a project result more favorable than may otherwise have resulted.

Free-drivers and market transformation - refers to individuals who are not involved in the project, but nevertheless adopt objectives due to the project's existence. An example may be a public awareness program that reaches further than the target audience, changing the habits of more households than was originally intended.

Snapback in energy use - refers to project participants who, after successfully implementing the project, take back some of the gains in efficiency by increasing energy use. For example, an individual reduces energy use by 10 percent through improvements in air conditioning efficiency. However, after energy savings have been realized, the thermostat is turned down to increase coolness, resulting in final energy savings of only 5 percent.

Persistence of program savings over time - takes into account any deterioration over time, including snapback, loss of interest by participants, etc.

Interaction effect of multiple programs or measures - includes any overlap of multiple measures, and accounts for the fact that savings from measures installed together are typically less than if they were installed independently.

[1] World Bank, 1994. *Greenhouse Gas Abatement Investment Project Monitoring and Evaluation Guidelines.* Environment Department, The World Bank, Washington, D.C.

Effects of measures on multiple end-uses - occurs when a single conservation measure affects more than one end-use.

Other exogenous factors - includes several non-project influences such as economic downturns, changes in life style, participants dropping out of the project, etc.

Create Statistical Samples for Project and Reference Scenarios

Most DSM projects involve several groups of participants, particularly in the residential and commercial sector. It is impractical and costly for all participants to be involved in data collection and analysis project evaluation. This section provides two common statistical methods for selecting a sample of the overall population (all of the project participants) for analysis.

If the project to be analyzed has only a few participants, for example ten of the most energy intensive industries in a particular country, then determining a representative sample is unnecessary.

Both tools use the following inputs:

Sampling frame - the unit of observation to be used in the evaluation. In the residential sector, for example, this could be a household or a cluster of households.

Degree of precision - which is determined by the evaluator, is a standard statistical measure of the desired level of confidence (Z) that the sample will be representative of within a certain error (E). For example, the evaluation of a lighting efficiency project must be correct within E = ±10% with a 95% confidence level (Z). This means that an error greater than 10% would occur not more than five times in every 100 trials. It should be noted that the greater the degree of precision the greater the sample size and thus the cost of the evaluation. Table 3.4.1 gives common values of Z.

Sample mean method[2] - used when the evaluator wants to determine an average value for the population, such as the average monthly electricity consumption. Average consumption for the reference and project scenarios may be used to determine and compare respective GHG emissions.

[2] Weiss, Neil A. *Introductory Statistics.* Addison-Wesley Publishing Company, Inc., 1995. Page 457.

Formula A.7.1 Sample size using the sample mean method

Sample Size = $(S * Z / E)^2$

where,

S	=	standard deviation of the population, which is data specific and must be calculated[3]
Z	=	unit value associated with the desired level of confidence. Exhibit A.6-1 gives common values for Z
E	=	margin of error or value denoting allowable error

For example, given a building electricity project in Monterey, Mexico that uses improved technologies such as energy efficient lighting, climate control, etc., the evaluator needs to compare the mean (average) energy consumption for the reference and project cases. The sample size is determined based on a standard deviation of 55%. The desired level of confidence is 90%, resulting in Z = 1.64 (see Exhibit A.6-1). The desired margin of error = ± 5%. Using Formula A.6.1,

$$\text{Sample Size} = (0.55 * 1.64 / 0.05)^2 = 326$$

Proportion method[4] - Used when the evaluator wants to determine the proportion (or percentage) of a population that has a specified attribute. For example, in analyzing transportation projects, the evaluator is interested in all citizens of New Delhi that commute to work by bus. The population is all commuters, whereas the "population proportion" refers to commuters that use the bus.

Equation 3.4.2: Sample size using the proportion method

Sample Size = $0.25 * (Z / E)^2$

Table 7.4.1
Common Values for Z

Level of Confidence (%)	68.26	90.00	95.00	95.44	99.74	100.00
Standard Deviation (Z)	1.00	1.64	1.96	2.00	3.00	3.90

<u>Sampling procedures and methods</u>

Once the sample size has been determined, the evaluator must decide how the samples will be chosen. Table 3.4.2 gives three common methods with a description of each technique.

[3] Consult any standard statistics book for instructions
[4] Weiss, Neil A. *Introductory Statistics*. Addison-Wesley Publishing Company, Inc., 1995. Page 660.

Exhibit A.7-2
Sampling Procedures and Method

Sampling Method	Description
Simple random sampling	The sample units are drawn lottery style, where each unit has an equal chance of being drawn. It is advantageous in its simplicity, but is effective only when the population is relatively homogenous. For example, if the population consisted of businesses and households with different end use profiles, some sub populations may not be adequately represented.
Systematic random sampling	Every 5th sample is drawn until the proper sample size is reached. For example, if a sample of 400 is required from a total of 2,000 participants, the population is ordered by a particular attribute, say electricity consumption, and every 1 in 5 (400/2,000) is chosen. In this example, every 5th customer is chosen until a sample size of 400 is reached.
Stratified sampling	Designed for populations with several homogenous sub-groups within the overall population, i.e. monthly energy consumption. The evaluator divides the overall population into relevant sub-groups and uses either simple random or systematic random sampling methods to develop a sampling size.

Gather Data for Project and Reference Scenarios

Data Sources

The evaluator now must gather the relevant energy consumption data for establishing the reference and project scenarios. Accuracy balanced with practicality issues, such as cost and access to data sources, are key issues. Data sources for sampling include the following:

- billing data;
- metered data;
- sub-metered data; and
- surveys of electric services customers and trade allies.

Time Period: Project Life and Analysis Periods

The time period used for analysis is a key issue. If the project life is five years, when should the data analysis take place? At the end of the project? After ten years? After twenty years? The answer depends on several practical issues, including the expected longevity of the project, budgetary limitations, etc. The evaluator must judge when project impacts have settled into a sustainable and measurable pattern, and whether any extraneous issues have surfaced that may impact on the results of the analysis.

Collection Methods

There are three types of data gathering methodologies generally used in DSM project evaluation:

Facility supplied data - refers to data that are derived directly from the customers through metering, records, or utility bills. It is generally considered the most reliable method.
Facility Inspection or Auditing - through on-site inspection, the evaluator gains information on the physical characteristics of the entire facility or building, equipment in the facility, and operating conditions. This is considered a less reliable method than facility supplied data.

Customer supplied data - this data can be particularly valuable in determining the consumption patterns of customers and their attitude toward energy efficiency and conservation programs. The basic methods for data gathering are:

- on-site interviews,
- mail surveys, and
- telephone interviews.

The obvious drawback to customer supplied data are built-in biases. Surveys may be used at any stage of DSM program implementation, and are particularly advantageous for DSM projects because the consumer is a major stakeholder in the success of the project. Vital information may be obtained regarding acceptance of conservation practices that may indicate the likelihood of long-term success of the changes in energy use. Except in rare cases, the only practical survey method for developing countries is direct interviews with participants. The use of phones and mail is often too unreliable or may be unavailable for the population of interest.

Any of these data collection methods will work with a sample or population, with the choice dependent on a variety of factors. The evaluator must seek the most reliable set of data balanced with the type of DSM project, time and potential cost of the data gathering exercise. Exhibit A.6-3 presents the strengths and weaknesses of each methodology.

Exhibit A.7-3
Characteristics of Data Sources

Data Source	Strength	Weakness
1) Facility Energy Use Measurement	Accuracy based on meter	Measures present use, not change in energy; no explanatory power
End-use metering	Highest unit accuracy for end-use loads	Most expensive per unit; budget limitations result in high sampling error
Whole building metering	Accurately measures load for the entire consumer premises	Lower accuracy than end-use metering when used to indicate end-use loads
Customer billing data	Census eliminates sampling error; relatively inexpensive	Difficult to detect change in treated end-use when used alone; does not provide data on demand impacts
2) Facility Inspection/Audits	Collects causal technical factors best	Can be very time consuming; actual change cannot be measured
3) Information Supplied by Customer	Best for customer market data and attitudes	Error rate high on technical data
Mail survey	Low cost permits large sample	High error rate and risk of non-response bias; impractical in LDCs
Telephone survey	High response rate and lower error rate than mail surveys	Higher cost than mail surveys' impractical in LDCs
In-person interview	Lowest bias and error on customer questions, best for complex information	Higher cost

Source: World Bank, 1994. "*Greenhouse Gas Abatement Investment Project Monitoring and Evaluation Guidelines.* "Environment Department, Washington, D.C.

Data Analysis for Project and Reference Scenarios

At this point in the process it is assumed that a sample size was calculated and data has been gathered for the respective scenarios. The next step is to focus on analyzing the data to determine energy consumption for a scenario over a given time period. The method used will be chosen by the evaluator and depend primarily on practical issues such as data type, funding and time available for analysis, and the analysis tools available. Below is a brief description of common analysis methods. Engineering methods address on and off peak periods. Peak periods occur during times of the day when electricity demand increases. These periods typically are in the morning and evening when most customers are using the same energy services such as preparing dinner or using hot water to shower. These peak periods are important to utilities because extra generating capacity must be installed at the same cost as off peak capacity, but to meet the increased demand that may occur only 4-6 hours per day.

Engineering methods - relies on engineering calculations and direct measurements, such as equipment usage estimates, thermal load analyses, and end-use or whole facility metering.

Statistical methods - uses models to perform statistical comparisons or regression analysis of energy consumption. Statistical comparisons focus on mean energy consumption, while regression analysis looks at a more complex picture such as the impact of weather, household size, etc.

Combined methods - is a combination of engineering and statistical methods as described above. This approach can increase accuracy while reducing time and effort. There are several ways to enhance the success of data gathering and analysis by combining engineering, statistical analysis.

Calculating Energy Consumption and GHG Emissions for Reference and Project Scenarios

This section presents the process for calculation of energy consumption and net GHG emissions in the industrial, residential and commercial, and transport sectors related to the specified DSM project(s). Formulas are presented for specific applications. In addition, examples have been included for illustrative purposes. Exhibit A.6-4 lists a summary of the applications by sector that are discussed and presented in this section.

Exhibit A.7-4
Summary of Illustrative Case Studies of Demand Side Management Projects in Handbook

Formula	Application
	Industrial Sector
A.6.5	Annual energy consumption from annual production
A.6.6	Annual emissions calculations with one fuel
A.6.7	Annual emissions calculations with multiple fuels
	Residential and Commercial Sector
A.6.8	Constant load with fixed hours: when power consumption is known
A.6.9	Constant load with fixed hours: when energy consumption is known
A.6.10	Constant Load with Variable Hours or Fixed Hours to Variable Hours
A.6.11	Motors with constant load: calculating power consumption
A.6.12	Motors with constant load: calculating energy consumption
A.6.13	Changes in both load and operating hours
A.6.14	Variable load applications
A.6.15	Calculating GHG emissions given energy consumption
	Transport Sector
A.6.16	Emissions based on distance traveled
A.6.17	GHG emissions of electric vehicles

INDUSTRIAL SECTOR

The equations in this section focus on calculating GHG emissions based on industrial production applications. To calculate GHG emissions from electricity consumption due to commercial building operation and appliance use, see the discussion on residential and commercial sectors.

The first step to calculating GHG emissions from industrial processes is to determine the energy consumption per unit of production. This information may already be available from the company or can be measured using one of the data gathering techniques described above.

Formula A.7.5 Annual energy consumption from annual production

$$AE = EU * Pr$$

megajoules = megajoules/mtonne * mtonne

where,

AE = annual energy consumption (MJ)
EU = energy consumption per unit of production (MJ/MT)
Pr = annual production (MT)

Using the results from Formula A.6.5, Formulas A.6.6, and A.6.7 can be used to calculate greenhouse gas emissions.

Formula A.7.6 Annual emissions from a single fuel

$$Em = (Ae_{ref} - AE_{proj}) * F$$

$$\text{kilograms GHG} = (\text{kilojoules}_{ref} - \text{kilojoules}_{proj}) * \text{kilograms GHG / kilojoules}$$

where,

Em = annual emissions (kg GHG)
Ere^{f} = annual energy consumption (reference scenario) (kJ)
$Epro^{j}$ = annual energy consumption (project scenario) (kJ)
F = emissions factor (kg GHG/kJ)

$$Em = \sum (E_{ref} - E_{proj}) * F_j$$

$$\text{kilograms GHG} = \sum (\text{kilojoules}_{ref} - \text{kilojoules}_{proj}) * \text{kilograms GHG/kilojoules}_j$$

Formula A.7.7 Annual emissions from multiple fuels

where,

Em = annual emissions (kg GHG)
E_{ref} = annual energy consumption (reference scenario) (kJ)
E_{proj} = annual energy consumption (project scenario) (kJ)
F_j = emissions factor for fuel j (kg GHG/kJ)

Example 1 - Industrial Sector Energy Efficiency Project: Changes in Multiple Fuel

Five lumber mills in Brazil, which are owned by the same company, use steam-heated kilns to dry the wood. The primary fuel used to generate the steam is natural gas. Due to unreliable sources for the natural gas, the boilers also were outfitted to burn No. 2 fuel oil. A three year project was implemented to simultaneously improve boiler efficiency as a money saving venture and to reduce CO_2 emissions.

Define the DSM Objective: Developing the Reference and Project Scenarios - Calculate annual CO_2 emissions from the natural gas and No.2 fuel oil used to generate steam in the boilers.

Create Statistical Samples for Project and Reference Scenarios - Since the population consists of five mills, a representative sample size is not needed.

Data Gathering for Project and Reference Scenarios - Data is supplied by the company using historic records of fuel purchases and projecting future use based on historic trends for the reference scenario.

Data Analysis for Project and Reference Scenarios -

Reference case: Production levels are expected to remain constant, however the fuel mix varies from year to year as a result of unreliable natural gas sources. Therefore, the reference case energy use will be calculated using average oil and gas purchases (based on plant records) for the three years prior to replacing the boiler. The average consumption of natural gas was given as 20.8 million cubic meters/yr, while fuel oil was 4,145,670 liters/yr.

Project case: The fuel consumption will differ from the reference case because of the improved boiler efficiency as well as year-to-year fluctuations in the fuel mix. During the three year project, the average natural gas consumption is estimated to be 21.9 million cubic meters/yr, while fuel oil consumption estimated to be 1,987,650 liters/yr.

Calculate Energy Consumption GHG Emissions for Project and Reference Scenarios -

Only data on the amount of fuel purchased was provided by the company as described above. Therefore, it was necessary to convert the fuel amount into energy units.

Natural gas = Annual Consumption * Energy Content / Unit Consumption

Natural gas_{ref} = 20.8 {million cubic meters/yr * 34,538 kJ/ cubic meters = 801 billion kJ/ yr

Natural gas_{proj} = 21.9 million cubic meters / yr * 34,538 kJ/cubic meters = 843 billion kJ/yr

Net emissions reductions are calculated from the net change in energy consumption and the emission factors. Natural gas has an energy value of 1,032 Btu/cubic foot, so the energy content of the natural gas used and the associated emissions are calculated as the following:

Em_{ref} = 801 billion kJ/yr * 50.1×10^6 MT CO_2 /kJ = 40,117 MT CO_2 / yr

Em_{proj} = 843 billion kJ/yr * 50.1×10^6 MT CO_2/EJ = 42,230 MT CO_2 /yr

No. 2 fuel oil is a form of distillate fuel oil:

Oil_{ref} = 4,145,670 liters/yr * 34,705 kJ/liter = 160 billion kJ/ yr

Oil_{proj} = 1,987,650 liters/yr. * 34,705 kJ/liter = 77 billion kJ/ yr

Em_{ref} = 160 billion kJ/ yr * $84x10^6$ MT CO_2 / EJ = 12,699 MT CO_2/ yr

Em_{proj} = 77 billion kJ / yr * $84x10^6$ MT CO_2 / EJ = 6,101 MT CO_2 / yr

As a result of the project, natural gas use and associated emissions are projected to increase while oil use and associated emissions go down relative to the reference case. The resulting changes in emissions follow:

For natural gas:

Em $_{ref}$ - Em sub proj = - 2,568 MT CO_2 / yr (an increase)

For oil:

Em $_{ref}$ - Em sub proj = 6,954 MT CO_2 / yr (a decrease)

Total net CO_2 Emissions = 6,954 - 2,568 = 4,386 mtonnes CO_2

No other effects within or outside the plant were anticipated. The total reportable emissions decrease is 4,386 metric tons of carbon dioxide.

RESIDENTIAL AND COMMERCIAL SECTOR: BUILDINGS AND APPLIANCE APPLICATIONS

Estimating changes in GHG emissions due to the introduction of DSM projects in the residential and commercial sector focuses on energy consumption from electricity use, primarily for building operations such as lighting and climate control. This section also is relevant to appliance use at home or in a business.

All of the equations described below involve variations in load (power required for device operation) and/or hours of operation:

Formulas A.7.8 and A.7.9: DSM Projects with Constant Load with Fixed Hours

In this project type, the power or energy provided is constant as well as the hours of operation for each day. Examples include exit signs, which require the same amount of energy twenty four hours/day, or street lights, which run at a constant load an average number of hours each year or season:

Formula A.7.8: When power consumption is known:

$$AES = H * N * (P_{ref} - P_{proj})$$

$$\text{kilowatthours / year} = \text{hours / year} * \text{Units} * (\text{kilowatts}_{ref} / \text{unit} - \text{kilowatts}_{proj} / \text{unit})$$

where:

AES	=	net annual energy savings resulting from project (kWh/yr)
H	=	annual hours of operation (hours/year)
N	=	Number of units replaced. If all the units replaced are grouped into an overall power consumption value, then set N = 1. (units)
P_{ref}	=	reference case power requirement (kW/unit)
P_{proj}	=	project scenario power requirement (kW/unit)

Exhibit A.7-5
Estimated Hours of Operation for Selected Technologies
(hours)

Technology	Annual hours of operation (H)
Motors with constant load	8,500
Exit sign light replacements	8,760
Street lights	4,000

Source: *Sector-Specific Issues and Reporting Methodologies Supporting the General Guidelines for the Voluntary Reporting of Greenhouse Gases under Section 1605(b) of the Energy Policy Act of 1992*: Volume I. U.S. Department of Energy. 1994. Page 2.14.

Formula A.6.9: When Energy Consumption is Known

$$AES = N * (E_{ref} - E_{proj})$$

$$\text{kilowatthours / year} = \text{units} * (\text{kilowatthours}_{ref} / \text{unit-year} - \text{kilowatthours}_{proj} /\text{unit-year})$$

where,

E_{ref} = net annual energy use of appliance (reference scenario) (kWh/unit-year)

E_{proj} = net annual energy use of appliance (project scenario) (kWh/unit-year)

N = Number of units replaced. If all the units replaced are grouped into an /all power consumption value, then set N = 1 (units)

Formula A.7.10 Constant Load with Variable Hours or Fixed Hours to Variable Hours

Formula A.6.10 may be used in two applications:

When the load is constant but the hours vary. For example, the use of lighting within a household may vary dramatically depending upon the daily schedules and energy needs of the occupants.

When the load is constant but due to the implementation of the DSM project, hours of operation change from fixed to variable hours. For example, a worker that originally kept the lights in the office on whether she was using the room or not. Due to the DSM project, the lights are turned off when the room is not in use. However, the changing schedule of the worker creates a varying number of hours each day that the lights are in use.

The equation for assessing the net annual energy savings under these conditions now becomes:

$$AES = N * P * (H_{ref} - H_{proj})$$

$$\text{kilowatthours} = \text{units} * \text{kilowatts / unit} * (\text{hours}_{ref} - \text{hours}_{proj})$$

Formulas A.7.11 and A.7.12: Estimating Power and Energy Consumption Savings of Motors with Constant Load

Formula A.6.11: Calculating Power Consumption

$$P = (PR * LF / eff)$$

$$\text{kilowatts / unit} = (\text{kilowatts} * \text{load factor / unit-motor efficiency})$$

where,

P = Power consumption (kW/unit)
PR = Power rating for motor (kW/unit)
LF = Load factor
eff = Motor efficiency

Formula A.6.12: Calculating Energy Consumption

$$E = P * H * N$$

$$\text{kilowatthours / year} = \text{kilowatts / unit} * \text{hours / year} * \text{units}$$

where,

E = Annual Energy Consumption (kWh/year)
P = Power use/motor (kW/unit)
H = Hours of operation/unit/year (hours/year)
N = Number of units operating (units)

Formula A.7.13 DSM Projects Leading to Changes in Both Load and Operating Hours

Formula A.6.13 can be applied when the project results in changes to both the power requirements and hours of operation. Since E = P * H, Formula A.6.13 is another way to express Formula A.6.8.

$$AES = N * [(P_{ref} * H_{ref}) - (P_{proj} * H_{proj})]$$

$$\text{kilowatthours} = \text{units} * [(\text{kilowatts / unit}_{ref} * \text{hours}_{ref}) - (\text{kilowatts / unit}_{proj} * \text{hours}_{proj})]$$

Formula A.7.14 Estimation of Energy Savings of Variable Load Applications

Variable (or partial) loading occurs when a device has a continuously changing load placed on it. The most common example are motors with several (or varying) speeds such as a fan with low, medium, and high options.

$$AES = RC * \sum[H_j * PLF_j * (UP_{ref} - UP_{proj})]$$

kilowatthours / year = unit capacity * $\sum$[m j [hours$_j$ * factor$_j$ * (kilowatts / unit$_{ref}$ - kilowatts / unit$_{proj}$)]

where;

RC	=	rated capacity of the appliance
H_j	=	annual hours of operation of appliance j (hours/year)
PL_{Pj}	=	load factor of appliance j
UP	=	measured power per unit of performance (kW/unit)

Formula A.7.15 Calculating Net GHG Emissions from Above Formulas (A.7.8 to A.7.14)

The results of Formulas A.6.8 to A.6.14 can be used as input in Formula A.6.15 to determine GHG emissions.

$$Em_j = \sum(AES_k * F_j k)$$

kilograms GHG$_j$ = $\sum$ (kilowatthours$_k$ * kilograms GHG / kilowatthours $_j$k)

where

Em = the net annual emissions of greenhouse gas j that results from the energy-conservation activity (kg GHG).

AES_k = the net annual energy savings of fuel k resulting from the energy-conservation activity (kWh)

F_{jk} = emissions factor for greenhouse gas j associated with fuel k (kg GHG/kWh)

TRANSPORTATION SECTOR

There are several options available to transport planners interested in improving the efficiency of transportation systems:

Marketing vehicles with lower emissions - includes the introduction of vehicles that are either more fuel efficient or use cleaner fuels. Data on existing vehicle performance is usually available from the manufacturer. Data for a specific vehicle or a fleet of vehicles may be derived by measuring the amount of fuel consumed for a given distance traveled (km/l).

Formula A.7.16 Emissions based on Distance Traveled

$$Em = D * F_j$$

kilograms GHG = kilometers * kilograms GHG / kilometer where,

Em	=	emissions for reference case
D	=	distance traveled (tonne-miles)
F_j	=	emission factor CO_2/unit distance (kg/tonne-mile)

Note: All of these projects are reporter designed, which indicates that the reporter must estimate the value of ef from actual data

$$\text{Net Annual Emissions Reduction} = \text{Emissions}_{ref} - \text{Emissions}_{proj}$$

Improving vehicle operation and maintenance - there are a number of efficiency options included in operation and maintenance, such as improving driving patterns, implementing vehicle inspection programs, and making routes for fleet vehicles more efficient. However, many of these options may prove quite difficult in a developing country environment due to lack of infrastructure and/or institutional capabilities to monitor standards (e.g. annual inspections).

Accelerating vehicle scrappage - older vehicles generally pollute more than newer ones. The average age of the vehicles in a city usually is directly correlated with the amount of air pollution generated from the transportation sector [REF]. A new project idea is for the government to introduce incentives to owners of older cars to replace them with more efficient models. The incentives could be in the form of rebates or tax incentives.

Introducing alternative fuels - as technology improves and costs decline, electric vehicles, natural gas fueled vehicles, and other alternative options have become available. These fuels result in less GHG emissions than diesel or gasoline powered cars. Formula A.6.17 provides the calculation for electric vehicles.

$$Em = El * F_j$$

$$\text{kilograms GHG} = \text{kilowatthours} * \text{kilograms GHG / kilowatthour}_j$$

Equation 13 GHG Emissions of Electric Vehicles

where,

Em = emissions of GHG j due to operation of vehicle (kg GHG)
El = energy consumption (kWh)
F_j = emissions factor for GHG j (grams/kWh)

Example 3 - Estimating Emissions Reductions Resulting from Improved Fuel Economy

A project in Mexico has been implemented through the government to increase the average fuel efficiency of vehicles sold in Mexico. The objective is to reduce pollution from the vehicles being placed in service in the next five years with the goal that this will stimulate consumer demand to continue the trend.

A major vehicle supplier has agreed to work with the government by redesigning a current model to improve fuel efficiency. The year before the project, the manufacturer sold 5,000 of the current low efficiency (kmpl) models. In the first year of the project, the manufacturer sold 5,000 of the improved model. No changes appear to have occurred in /all market share relative to competitors. All vehicles are fueled with gasoline. Manufacturer tests show that fuel economy in the original vehicle is 11 km/l, while the improved model is 13 km/l. The manufacturer also has data on distance traveled annually for vehicles that used their facility for service: 16,000 km for the original vehicle and 17,200 km for the more efficient vehicle.

Step 1: Define the DSM Objective: Develop the Reference and Project Scenarios - Calculate the emission reductions due to the project of the following GHGs: carbon dioxide (CO_2), methane (CH_4), and Nitrous oxide N_2O)

Step 2: Create Statistical Samples for Project and Reference Scenarios - The manufacturer has supplied fuel efficiency and annual distance traveled data that is considered sufficiently reliable. Therefore no sample will be necessary for data gathering and analysis.

Step 3: Gather Data for Project and Reference Scenarios - Data on fuel efficiency and annual distance traveled has been provided by the manufacturer.

Step 4: Analyze Data for Project and Reference Scenarios -

Reference scenario: The reference scenario is based on what the emissions would have been / a five year period in the absence of the project, assuming that sales of the original model would have been the same in later years. It is assumed that the same holds true for the distance traveled also remains constant.

Project scenario: The improvement in fuel economy has led drivers to use their vehicles slightly more than the original model according to the manufacturer. Table 3.4.9 presents the data provided by the manufacturer.

	fuel efficiency (km/l)	annual distance traveled (km/yr)
Original model	11	16,000
Fuel efficient model	13	17,200

Step 5: Calculate Energy Consumption GHG Emissions for Project and Reference Scenarios -

Total Mileage

	No. of vehicles		km/vehicle		
Reference case:	5,000	*	16,000	=	80 million km
Project case:	5,000	*	17,200	=	86 million km

Total Fuel Use

Total annual fuel use is estimated as follows:

func Annual Fuel Use = Distance traveled / Fuel Efficiency

	km		km/l		
Reference case:	80 million	/	11	=	7.3 million liters
Project case:	86 million	/	13	=	6.6 million liters

GHG Emissions Estimation

Gross Annual Reference Case Emissions

func Annual Emissions = Annual Distance Traveled * Fm SUB gasoline + Annual Fuel Use * Ff SUB gasoline

GHG		distance traveled (10^6 km)		emissions factor (g/km)		Annual Fuel Use (10^6 l)		emissions Factor (g/l)		
N_2O	=	80	*	0.03	+	7.3	*	0.175	=	8.89 x10^6 kg/yr
CH_4	=	80	*	0.03	+	7.3	*	8.67	=	70.91 x10^6 kg/yr
CO_2	=	80	*	2.0	+	7.3	*	1,100	=	8,538 x10^6 kg/yr

Project Case Emissions

GHG		distance traveled (10^6 km)		emissions factor (g/km)		Annual Fuel Use (10^6 l)		emissions Factor (g/l)		
N_2O	=	86	*	0.05	+	7.3	*	0.175	=	5.58 x10^6 kg/yr
CH_4	=	86	*	0.05	+	7.3	*	8.67	=	67.58 x10^6 kg/yr
CO_2	=	86	*	2.0	+	7.3	*	1,100	=	8,202 x10^6 kg/yr

The results of the project follow:

N_2O: $Emissions_{ref}$ - $Emissions_{proj}$ = 8.89x10^6 kg - 5.58x10^6 kg = 3.31x10^6 kg (increase)
CH_4: $Emissions_{ref}$ - $Emissions_{proj}$ = 70.91x10^7 kg - 67.58x10^7 kg = 3.33x10^6 kg (decrease)
CO_2: $Emissions_{ref}$ - $Emissions_{proj}$ = 8,538x10^{10} kg - 8,202x10^{10} kg = 3.36x10^9 kg (decrease)

ANNEX 8
CALCULATION OF TRACE GASES FROM BIOMASS BURNING

If large areas of forests are converted to agricultural land and substantial quantities of wood are burnt this may result in the significant production of "trace" GHG's. These trace gases can be estimated and are detailed below. However, if only small areas of land are cleared, the production of trace gases may be insignificant and should be neglected when calculating GHG emissions.

All biomass burning calculations have two steps:

1) estimating total carbon released, and
2) applying emission ratios to estimate emissions of the non-CO_2 trace gases.

In the case of burning of cleared forests (and other land conversion if appropriate), step 1 entails the estimation of above and below ground biomass and the division of this biomass between the quantity left on site for burning that removed for processing and the below ground biomass left to decay. To complete the calculations, it is necessary only to add step 2 of the calculation - the release of non-CO_2 trace gases from current burning. If only small quantities are burnt in situ, then the trace gas production will be negligible.

Once the total carbon released from on site burning of cleared biomass has been estimated, the emissions of CH_4, CO, N_2O, and NOx can be calculated (Crutzen and Andreae, 1990). The total carbon released due to burning is multiplied by the emission ratios of CH_4 and CO relative to emissions of total carbon to yield total emissions of CH_4 and CO (each expressed in units of C). The emissions of CH_4 and CO are multiplied by 16/12 and 28/12, respectively, to convert to full molecular weights.

To calculate emissions of N_2O and NO first the total carbon released is multiplied by the estimated N/C ratio of the fuel by weight (0.0 I is a general default value for this category of fuel (Crutzen and Andreae, 1990)) to yield the total amount of nitrogen (N) released. The total N released is then multiplied by the ratios of emissions of N_2O and NO. relative to the total N released from the fuel to yield emissions of N_2O and NOx (expressed in units of N). To convert to full molecular weights, the emissions of N_2O and NO. are multiplied by 44/28 and 30/14, respectively. The molecular weight ratios given above for the emitted gases are with respect to the weight of nitrogen in the molecule. Thus for N_2O the ratio is 44/28 and for NOx it is 46/14. NO_2 has been used as the reference molecule for NO_2.

The trace gas emissions from burning calculation are summarized as follows:

- CH_4 Emissions = (carbon released) x (emission ratio) x 16/12
- CO Emissions = (carbon released) x (emission ratio) x 28/12
- N_2O Emissions = (carbon released) x (N/C ratio) x (emission ratio) x 44/28
- NOx Emissions = (carbon released) x (N/C ratio) x (emission ratio) x 46/14
- NO Emissions = (carbon released) x (N/C ratio) x (emission ratio) x 30/14

Exhibit A 8-1
GHG Emission Ratios for Open Burning of Cleared Land

Compound	Ratios
CH_4	0.012 (0.009 - 0.015)[1]
CO	0.060 (0.04 - 0.08)[2]
N_2O	0.007 (0.005 - 0.009)[3]
NO	0.121 (0.094 - 0.148)[3]

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.

Sources: Delmas 1993, Lacaux 1993, Crutzen and Andreae 1990.

ANNEX 9
MEASUREMENT OF ORGANIC CARBON IN ABOVE AND BELOW GROUND WOODY BIOMASS

Even though there may be more organic carbon in soils than in wood, the carbon stored in trees is greater than the **additional carbon** stored in the soil beneath the trees (see Exhibit 5-3). Also, the sequestration of carbon in wood, leaves, and other forest plants, directly affects the build up of organic carbon in forest soils.

Therefore, for proposed and actual projects, it is most important to obtain an accurate estimate of organic carbon in the different age classes of woody biomass formations such as woodlands, natural forests, plantations and all kinds of trees and shrubs outside the forest, particularly farm trees. **While soil carbon can only act as a store, the carbon in wood can be both a store and an energy source.** Thus, it can be, and is, substituted or used in place of fossil fuels. Also wood and other biomass can be converted into more convenient gaseous, liquid and solid energy forms.

Assumptions on Biomass Changes: Above and Below Ground

The amount of aboveground biomass affected by land use changes in the project assessment is calculated by multiplying the annual forest area (or savannas, grasslands, etc., if appropriate) converted to pasture or cropland or other land uses by the net change in aboveground biomass. This calculation is carried out for each relevant forest/grassland type. The **net change in above ground biomass** is the difference between the density (t dm/ha) of aboveground biomass on that forest/grassland prior to conversion, and the density of aboveground living biomass (t dm/ha) remaining as living vegetation, after clearing. The after- clearing value includes the biomass that regrows on the land in the year after conversion and any original biomass which was not completely cleared.

Exhibit A 9-1 provides a range of general values, for aboveground biomass in forests prior to clearing, which can be used as default data if more appropriate and accurate data are not available in a given country. However for a project area, measurements could be made from the actual or surrounding areas. For aboveground biomass after clearing, it is necessary to account for any woody vegetation that replaces the cleared vegetation. The recommended default assumption is that all of the original aboveground biomass is destroyed during clearing. If locally available data indicate that some fraction of the original biomass is left living after clearing, this should be added to the after clearing value.

Exhibit A 9-1
Dry Matter in Aboveground Biomass in Tropical Forests
tonnes dm/hectare

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

Note: Broad regional estimates of biomass densities are highly uncertain. Estimates based on destructive sampling involve direct measurements (weighing) of biomass harvested from an experimental site. Volume-based estimates are generally somewhat lower than those based on destructive sampling and are derived from FAO data on commercial wood volumes that are converted to mass units based on average wood densities and ratios of aboveground biomass to commercial biomass (i.e., expansion factors). Researchers agree that there is a great deal of variability from stand to stand and among subregions within large regions. For example, Brown and Lugo (1992) report biomass estimates ranging from 166 to 332 t dm/ha for individual stands in moist Amazonian forests. There are also some differences in the way different experts interpret the available data to produce averages. Fearnside (1993) has documented similar ranges of variability from stand-to-stand and produced somewhat higher average estimates of aboveground biomass for the Brazilian Amazon than those of Brown and Lugo (1992). His estimates are:

	Average for Brazilian Forests Actually Cleared (1990)	
	Amazon	Brazilian Amazon
	t dm/ha	t dm/ha
Undisturbed forests	308	291
Secondary forests	NA	271

Fearnside (1992) and Brown and Lugo (1992) discuss in detail a number of possible explanations for the differences in results.

As in the case of land-use data, developing appropriate biomass growth data is a challenging task. In theory, above and below ground growth can be obtained directly by sampling the project area. An alternative approach is to use inventory or production data where one exploits volumetric data on marketable timber and uses a sequence of expansion factors to convert this to total stemwood, total above ground biomass volume, total biomass volume, and finally to dry weight.

Estimates of average annual accumulation of dry matter as biomass per hectare are presented for forests naturally regrowing by broad category by the IPCC. These values may be used as default values for growth rates in similar managed forest categories if no other information is available. For forests which are more intensely managed (e.g., with periodic thinning, restocking, etc.) annual growth increments could be quite different. Values for some typical plantation species are presented in Exhibit A 9-2 and also may be used as default values by the project analyst. As discussed in notes in these tables, average growth rates represent a great deal of variability within regions and even from site to site. It is always strongly recommended that measurements are taken from surrounding areas or that locally available data be used or developed for project purposes if possible (Exhibit A 9-3 and Exhibit A 9-4).

Exhibit A 9-2
Average Annual Increment of Biomass in Selected Plantation Species

Forest Type	Annual Increment in Biomass tonnes dm/hectare/year
Tropical	
Acacia spp.	15.0
Eucalyptus spp.	14.5
Tectona 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 (Pseudotsuga taxifolia)	6.0
Loblolly pine (Pinus taeda)	4.0

Sources: Derived from Brown et. al. 1986, Farnum et. al. 1983, IPCC/OECD/IEA/UNEP 1995.
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 by individual countries (as available). Additional temperate estimates by species and by country should be available in the countries.

Exhibit A 9-3
Variability in Densities of Tree Species

There is considerable variation in average densities for different tree species. While the broad average default values given in the text can be used for initial calculations, it is much better to use actual measured average values if available, or literature values specific to the dominant species in a particular forest. Dixon et al. (1991), for example give densities for over 150 individual species, which range from 0.31 to 0.86 g/cm^3. Other sources of wood densities include USDA Forest Service (1987), Cannell (1984), Dewar and Cannell (1992), UN ECE/FAO (1992), Nabuurs and Mohren (1993) and Hamilton (1985).

Exhibit A 9-4
Density of Selected Wood Species

Species	Volume m^3/tonne[1,2]	Density
Mangrove	1.08	0.806
Eucalyptus	1.40	0.621
Wattle	1.37	0.635
Commercial Forest Species	1.40	0.621
Non-Commercial Species	1.50	0.580
Bamboo/Scrub	1.40	0.621
Pines/Cypress	1.90	0.458
Tea	1.60	0.544
Coffee	1.70	0.512
Farm Species	1.70	0.512

1 At 13% moisture content wet basis (15% mcdb). Volume per air dry tonne

2 It should be noted that as logs dry out from green up to about 10% mcdb there is very little shrinkage, or the order of 2-3% from green to air dry logs, therefore the volume measure can be taken as constant.

Source: Openshaw 1986.

Fuelwood Consumption Accounting

In any forest project under consideration by the Bank, significant amounts of biomass may be removed from forests on an informal basis (i.e., they are never accounted for in commercial statistics). This is generally true where "traditional" biomass fuels make up a major share of total fuel used in residences and small commercial enterprises. According to the IPCC methodology, an alternative approach, referred to as "Fuelwood Consumption Accounting", can be used. Estimates of fuelwood consumption are made based on per capita consumption data and population statistics. This accounting should also consider charcoal consumption, and "back out" an estimate of the wood raw material consumed in the traditional charcoal manufacture. A good estimate is four to five tonnes of dry wood are required to make one tonne of lump charcoal. Results from this type of accounting can be used in calculating **changes in forest and other woody biomass stocks**. However, dead wood may be the collected fuel, but usually this is not accounted for in the measurement of standing stock. If significant amounts of biomass (slash) are burned on site during harvest, then emissions from this burning should be treated as described for burning associated with forest or grassland conversion in the next section. The result of this calculation can then be combined with any commercial and non-commercial harvest amounts to produce a total amount of biomass lost from managed forests.

Measurement of Organic Carbon in Soils

Soils usually hold a greater store of organic carbon per unit area than is contained in the biomass growing on the same area. The amount of organic carbon [5] in soils depends on soil type, soil depth, climate and/or elevation and land use. Several general principles of carbon measurement and relative storage are useful rules of thumb to remember when comparing and assessing forestry and other land-use projects. These relationships are:

- From measurements undertaken in various countries, in different soil types and under different land uses, it has been shown that, **on average, there is a greater storage of organic carbon in forest soils than in grassland soils, which in turn have a larger amount of organic carbon than do arable agricultural soils** (Bouwmann, A. F. Ed. 1990. Soils and the Greenhouse Effect).

- The same table also demonstrates that the greatest concentration of soil carbon is close to the surface and it decreases with increasing depth. **Thus by promoting forest management and tree planting, there is a double accumulation of carbon, namely in the trees and in the soils beneath the trees.**

The greater concentration of organic soil carbon under trees could be due to a number of facts; agricultural soils are frequently tilled and, therefore, the vegetable matter in the soils breaks down more readily; there is a much larger accumulation of litter on the forest floor than in other land uses; tree roots when they die contain more lignin than other plants, this decomposes very slowly; periodic grassland and woodland fires produce some charcoal which becomes incorporated into the soil. Most importantly, tree roots penetrate far more soil horizons than do other forms of plant life and there is a much denser mat of roots and rootlets per unit volume than for annual plants; these small roots and rootlets constantly die and are replaced. All these reasons could account for the difference in organic soil carbon content between the various land uses. However, whenever trees are incorporated into any land use system, there should be a measurable increase in the soil carbon content.

Converting forest land to arable agriculture will generally result in a loss of soil carbon as well as the loss of carbon in the woody tissue. This is also true when primary forest is converted into grasslands for animal grazing although secondary forest soils may contain about the same amount of organic soil carbon as grasslands on similar sites.

Thus a project that opens up forest land to arable or pastoral agriculture will lead to a reduction of total organic carbon. On the other hand planting trees on abandoned farm land will increase soil carbon and biomass carbon. Of course the loss of soil carbon with a land use change from forest to arable agriculture will vary over time, being rapid at first and than gradually slowing down until it reached a base level. This is why it is important to undertake periodic soil samples to determine the change in soil carbon content. IPCC assume a linear loss of soil carbon over a 25 year period.

In temperate systems, most of the soil carbon is released in the first 5 years after forest clearing; the rest is released over the next 20 years (Houghton et al. 1983; Houghton 1991). The issue of soil carbon change following land-clearing in the tropics is an important research topic. There is evidence that there is a rapid soil carbon loss followed by soil carbon accumulation in pastoral agriculture, depending upon the

[5] Inorganic carbon can be found naturally in many soils. Also limestone or lime may be added to soils to increase the pH, or reduce the acidity of the soil.

type of grasses that are used (Fearnside 1980, 1993; Buschbacher 1984; Cerri et al. 1988; and Lugo et al. 1986).

Regardless of the crop growing on the project land, soil carbon can be increased by manipulating management practices, such as pH level, nitrogen concentration, other minerals nutrient levels. These various practices are described in a recent book entitled "Soil Management and the Greenhouse Effect" (Lal et al. (ed.) 1995).

ANNEX 10
NITROGEN FIXATION AND GHG EMISSIONS

Much of the "fixed" N is used by the plants themselves, but some is released to the soil when root nodules die, tree leaves are mulched into the soil, manure is returned to the soil or the plants are ploughed under. Thus this nitrogen becomes available to other plants which usually stimulates biomass production, and in turn increases the storage of soil carbon. Generally there is a fixed relationship between the amounts of carbon and nitrogen in the soil. Hence, the higher the nitrogen content, the higher the carbon content. (Lal R et al [Ed.] 1995). **Therefore, one way to increase the carbon content of the soil is to increase its nitrogen content,** provided soil conditions are suitable for the plants to absorb this N. This should reduce the amount of nitrogen in the atmosphere. Nitrous oxide, (N_2O) is a potent GHG, for it has a forcing effect of 270 compared to CO_2.

Most artificial nitrogen fertilizer is made through a process of turning atmospheric nitrogen into solid compounds. About 35 Giga Joules of energy (0.8 tonnes of oil) are used to produce 1 tonne of urea based fertilizer. Incorporating nitrogen fixing plants, particularly trees, in the farming system should reduce the requirements for artificial fertilizers, provide nitrogen in situ and boost the storage of organic carbon in biomass and the soil. Some of this nitrogen is quickly broken down into nitrogen gases and released back into the atmosphere. However, it is debatable whether this should be counted as an additional source of GHG, because it was originally absorbed from the atmosphere.[6] What should be counted is the **NET fixation of nitrogen** either naturally or artificially. Obviously if N is fixed by plants there is no fossil fuel used in the manufacturing and distribution process.

By incorporating nitrogen fixing plants, or intensifying their use, into systems that otherwise would not receive N fertilizers, it can be assumed that this is an additional fixation of nitrogen. Again, for a project, the increased application of artificial fertilizer over a base period can be counted as a net addition. Soil sampling at frequent intervals will indicate the increase of N and C. However, an estimate can be made using existing data. A method for calculating the amount of nitrogen fixed by trees is discussed and an example under different rainfalls is given. It should be stated that if soils already have sufficient nitrogen to adequately meet the requirements of plant growth, then trees and other nitrogen fixing plants will fix little, if any, of it. Thus, there is a saturation point for nitrogen, after which it will leach easily from the soil or be turned back to the gaseous form. Of course, when plants start to use up nitrogen, deficits may occur and at this point, nitrogen fixing may commence.

Thus, when testing for soil carbon, tests on the quantity of nitrogen in the different soil horizons should be undertaken. In fact, it would be prudent to undertake a complete soil analysis to determine the status of the three primary growth element, namely, nitrogen, phosphorous and potassium, (N, P, K) The analysis should also ascertain if there are any trace element deficiencies and find out the soil acidity/alkalinity, (pH) or hydrogen ion concentration. This information is vital to determine the soil treatment prescription. In many tropical soils, it is too high a soil acidity, rather than lack of NPK, which is inhibiting plant growth. Thus the ideal treatment may be to add a cheap calcium compound, (lime, limestone or calcium silicate), rather than expensive fertilizers, (Uehara G. in Lal et al. 1995).

Tree species are amongst the highest fixers of nitrogen compared to other plants. For example, *Sesbania* species are reported to fix over 500 kg of N/ha/year. and *Leucaena spp.* nearly 600 kg of N/ha/yr, whereas the average is estimated to be 200 kg N. (FAO 1983 & 1984). Both these species grow best with rainfall greater than 1000 mm per year and the above recordings were probably in areas where the average rainfall is about 1500 mm per year. In lower rainfall areas, but with suitable tree species, such as *Prosopis spp.* average wood

[6] When nitrogen is fixed from the atmosphere, either by plants or through an energy intensive chemical reaction such as the Haber-Bosch process, most is elemental nitrogen (N_2), but some will be from oxides of nitrogen.

growth of between 5 t and 7 t per ha. per year is normal. The leaves and pods of these trees will contain about 100 kg. of N per ha., thus the total amount of nitrogen fixed per ha. could be of the order of 150 kg.

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