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Intergovernmental Panel on Climate Change

Greenhouse Gas Inventory Workbook

IPCC Guidelines for
National Greenhouse Gas Inventories

Volume 2

OECD
OCDE

IPCC
IPCC WGI Technical Support Unit
Hadley Centre
Meteorological Office
London Road
Bracknell, RG12 2SY
United Kingdom

Fax: (44 1344) 856 912

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ACKNOWLEDGEMENTS

The present IPCC Guidelines for National Greenhouse Gas Inventories have been approved by the Scientific Assessment Working Group of the IPCC at Maastricht in September 1994 and subsequently adopted by the IPCC at its 10th session in Nairobi (10-12th November 1994). The Guidelines represent a first and substantial step towards the assembly and wide understanding of the methodologies needed for inventory construction. Their preparation has been a mammoth task involving many hundreds of experts and users and financial and other support from many countries and international organisations. I take this opportunity to acknowledge their financial and non-financial contributions and to thank all the donors sincerely. It would not be practical for me to name individually all those who have so willingly assisted this IPCC/OECD joint programme and helped to bring it to fruition. I would like, however, to identify the key groups and their leader, not only in their own rights but as the representatives of the many who have supported them.

Financial support for the programme was provided by the United Nations Environment Programme/Global Environment Facility, the Environment Directorate of the Organisation for Economic Cooperation and Development, the International Energy Agency, the Commission of the European Communities, and the governments of Australia, Canada, France, Germany, Italy, Japan, the Netherlands, Norway, Sweden, Switzerland, the United Kingdom and the United States of America. Significant non-financial contributions and resources in kind came from the European Environment Agency, IEA, OECD, UNEP, Japan, the Netherlands (in particular, the National Institute for Public Health and Environmental Protection or RIVM), the UK, and the USA.

The major, substantive content of the Guidelines was collected, assessed and assembled by groups of experts each covering the science of emissions within their specialist areas. The leaders of the groups are identified below and they wish to acknowledge, as I do, the crucial part played by the innumerable experts who enthusiastically helped in this undertaking.

The three volumes of the Guidelines were assembled and edited by the Technical Support Unit of Working Group I of the IPCC and the secretariats of the OECD and the IEA. I thank Paul Schwengels (Programme Manager), Jan Corfee-Morlot and Hans Sperling at the OECD and Tim Simmons and Karen Tréanton at the IEA for their leading roles. I, at the same time, recognise the unfailing support of their colleagues over the past three years.

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These Guidelines form part of the IPCC Special Report to the first session (Berlin, 28 March to 7 April 1993) of the Conference of the parties to the UN Framework Convention on Climate Change. The other parts are:

- Report on Radiative Forcing of Climate Change 1994 with a Summary for Policymakers;
- An Evaluation of the IPCC 1992 Emission Scenarios also with a Summary for Policymakers;
- The IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations.

The first two are published together and the last is a stand-alone volume. The Special Report was adopted by the IPCC at its tenth session (Nairobi, 10-12 November 1994).

Professor B Bolin
Chairman, IPCC

Expert Groups

Methane and Nitrous Oxide Expert Group Steering Committee
André van Amstel, Paul Crutzen, Elaine Matthews, A P Mitra, Nigel Roulet, Paul Schwengels

Methane from Rice Production
Co-chairs: K Minami and M A K Kalil

Methane from Coal Mining
Co-chairs: Alan Williams and Dina Kruger

Methane from Oil and Natural Gas Activities
Co-chairs: Audland Rosland and Craig Ebert

Methane from Ruminant Animals and Waste
Co-chairs: Michael Gibbs, Robert Leng, Jonathan Woodbury, Dr Ramasami

Methane from Landfills and Wastewater Treatment
Co-chairs: Susan Thornloe and Elizabeth Aitchison

GHGs from Land Use Change, Forestry and Burning
Co-chairs: Robert Delmas and Dilip Ahuja

Methane from Industrial Sources
Chris Veldt, Lee Beck, Jan Bertowski and Jos Oliver

Nitrous Oxide from Agricultural Soils
B H Byrnes, A R Mosier, A F Bowman, P A Leffelaar

Nitrous Oxide from Combustion and Industrial Processes
G De Soete and A McCulloch

PREFACE

Signature of the UN Framework Convention on Climate Change (UNFCCC) by around 150 countries in Rio de Janeiro in June 1992 indicated widespread recognition that climate change is potentially a major threat to the world's environment and economic development. Human activities have substantially increased atmospheric concentrations of greenhouse gases, thus perturbing the earth's radiative balance. According to projections from climate models, a global rise of temperature is a likely consequence. The potential impacts of climate change such as sea level rises and changes in local climate conditions including temperatures and precipitation patterns, could have important negative impacts on the socio-economic development of many countries.

The ultimate objective of the Convention is the stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level is to be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change. The Convention also calls for all Parties to commit themselves to three objectives:

- To develop, update periodically, publish, and make available to the Conference of Parties their national inventories of anthropogenic emissions by sources and removals by sinks, of all greenhouse gases not controlled by the Montreal Protocol.
- To use comparable methodologies for inventories of greenhouse gas emissions and removals, to be agreed upon by the Conference of Parties.
- To formulate, implement, publish and update regularly national programmes containing measures to mitigate climate change by addressing anthropogenic emissions.

The IPCC *Guidelines* are intended to assist the Parties directly in implementing the first two of these requirements. They have been under development for several years, in anticipation of this need.

By the time of the Second World Climate Conference in Geneva in October - November 1990, the need for a standard methodology for compiling national emission inventories was obvious. Under the auspices of the Organisation for Economic Co-operation and Development (OECD) and the International Energy Agency (IEA), with support from the USA, the UK and Norway, an initial compendium of methods was compiled. This document covered six direct and indirect greenhouse gases – carbon dioxide, methane, nitrous oxide, carbon monoxide, nitrogen oxide and non-methane volatile organic compounds. Chlorofluorocarbons (CFCs) and other substances already accounted for under the Montreal Protocol were intentionally excluded from the compendium. The document was discussed in detail by a meeting of experts (including many representatives of non-OECD countries) in Paris in February 1991. It was then adopted in a slightly modified form at the fifth session of the Intergovernmental Panel on Climate Change (IPCC) in March 1991 as the starting point for a set of IPCC *Guidelines* to be used by countries drawing up national inventories of greenhouse gas emissions and removals.

Development of the *Guidelines* has been undertaken by the Scientific Assessment Working Group (WGI) of the IPCC, working in close collaboration with the OECD and the IEA under the IPCC/OECD programme on emissions inventories. The objectives of the programme are:

- to develop and refine an internationally agreed methodology and software for calculation and reporting of national net emissions;
- to encourage widespread use of the methodology by countries participating in the IPCC and Parties to the UN Framework Convention on Climate Change;
- to establish procedures and a data management system for collection, review and reporting of national data.

The IPCC *Guidelines for National Greenhouse Gas Inventories* consist of three volumes: the *Greenhouse Gas Inventory Reporting Instructions*, the *Greenhouse Gas Inventory Workbook* and the *Greenhouse Gas Inventory Reference Manual*. The *Guidelines* include simple, default methods and assumptions covering the major sources and sinks of greenhouse gases, and also discuss more detailed methods. Countries have the option of using various methods and levels of detail depending on their own needs and capabilities. The *Guidelines* also provide a common reporting and documentation framework for all inventories. This is needed to allow for consistent comparison of national estimates even though they may have been prepared with varying methods.

It is essential that these *Guidelines* are approved internationally, and considerable effort has been expended to ensure this result. The methodology has been discussed, evaluated and refined through an international process which has included:

- wide dissemination of early drafts and collection of comments from national experts;
- testing of methods through development of preliminary inventories;
- country studies which ensure that methods are tested in a wide variety of national contexts;
- technical workshops held in several locations including Western Europe, Africa, Latin America, Central Europe and Asia;
- informal expert groups convened to recommend improvements on specific aspects of the methodology.

The above activities all contributed to the development of the draft IPCC *Guidelines*. This draft was then circulated world-wide, in six UN languages for an extensive review by national and other technical experts. This review resulted in significant improvements to the *Guidelines*. The IPCC *Guidelines* were approved in November 1994 and then published. In March 1995, the Conference of the Parties of the Framework Convention on Climate Change will take a final decision about the use of the *Guidelines*, in connection with the UNFCCC.

The development of the IPCC *Guidelines* is an iterative process and Phase I of this process has now been completed. It is anticipated that the *Guidelines* will need to be updated periodically for several years as better data and scientific understanding support better estimation methods. Work is continuing on the development of improved methods that can be proposed, reviewed and approved by the IPCC in the future. From this point, the work of the IPCC/OECD programme will continue in several areas:

- some gases not covered in the current draft (e.g., hydrofluorocarbons - HFCs, tetrafluoromethane - CF_4, sulphur hexafluoride - SF_6, and hexafluoroethane - $C_2 F_6$) will be added to the current methodology;
- some gases, e.g., nitrous oxide - N_2O will be given a more complete treatment in future supplements to the *Guidelines*;
- the current methodologies included in the *Guidelines* will be reviewed in the light of evolving scientific understanding and will be updated where appropriate.

Future work in the IPCC/OECD programme will continue to be supported by all of the mechanisms for international communication and consensus (e.g., expert groups, workshops, country studies) that have been used in the past. The scope and timing of future updates to the IPCC *Guidelines* will be determined on the basis of guidance from the IPCC and in consultation with the INC/COP.

OVERVIEW OF THE IPCC GUIDELINES

This document is one volume of the *IPCC Guidelines for National Greenhouse Gas Inventories*.

The series consists of three books:

- THE GREENHOUSE GAS INVENTORY REPORTING INSTRUCTIONS
- THE GREENHOUSE GAS INVENTORY WORKBOOK
- THE GREENHOUSE GAS INVENTORY REFERENCE MANUAL

These books together provide the range of information needed to plan, carry out and report results of a national inventory using the IPCC system.

The *Reporting Instructions* (Volume 1) provides step-by-step directions for assembling, documenting and transmitting completed national inventory data consistently, regardless of the method used to produce the estimates. These instructions are intended for all users of the IPCC *Guidelines* and provide the primary means of ensuring that all reports are consistent and comparable.

The *Workbook* (Volume 2) contains suggestions about planning and getting started on a national inventory for participants who do not have a national inventory available already and are not experienced in producing such inventories. It also contains step-by-step instructions for calculating emissions of carbon dioxide (CO_2) and methane (CH_4), as well as some other trace gases, from six major emission source categories. It is intended to help experts in as many countries as possible to start developing inventories and become active participants in the IPCC/OECD programme.

The *Reference Manual* (Volume 3) provides a compendium of information on methods for estimation of emissions for a broader range of greenhouse gases and a complete list of source types for each. It summarises a range of possible methods for many source types. It also provides summaries of the scientific basis for the inventory methods recommended and gives extensive references to the technical literature. It is intended to help participants at all levels of experience to understand the processes which cause greenhouse gas emissions and removals to occur and the estimation methods used in compiling inventories.

Contents of the IPCC Guidelines

All three volumes begin with the following sections:

Acknowledgements
Preface
Overview of the IPCC Guidelines

The contents of each volume are as follows:

Volume 1: Greenhouse Gas Inventory Reporting Instructions

Introduction to the Reporting Instructions
Chapter 1: Understanding the Common Reporting Framework
Chapter 2: Reporting the National Inventory
Tables: Standard Data Tables
  Summary Report Tables
  Overview Table
Annex 1: Managing Uncertainties
Annex 2: IPCC and CORINAIR Source Categories
Glossary

Volume 2: Greenhouse Gas Inventory Workbook

Introduction to the Workbook
Module 1: Energy
- Combustion-Related Emissions
- Fugitive Emissions

Module 2: Industrial Processes
- CO_2 from Cement Production

Module 3: Solvent and Other Product Use
Module 4: Agriculture
- Domestic Livestock
- Rice Cultivation
- Prescribed Burning of Savannas
- Field Burning of Agricultural Residues

Module 5: Land Use Change and Forestry
- Changes in Forest and Other Woody Biomass Stocks
- CO_2 Emissions from Forest and Grassland Conversion
- On-Site Burning of Forests: Emissions of Non-CO_2 Trace Gases
- Abandonment of Managed Lands

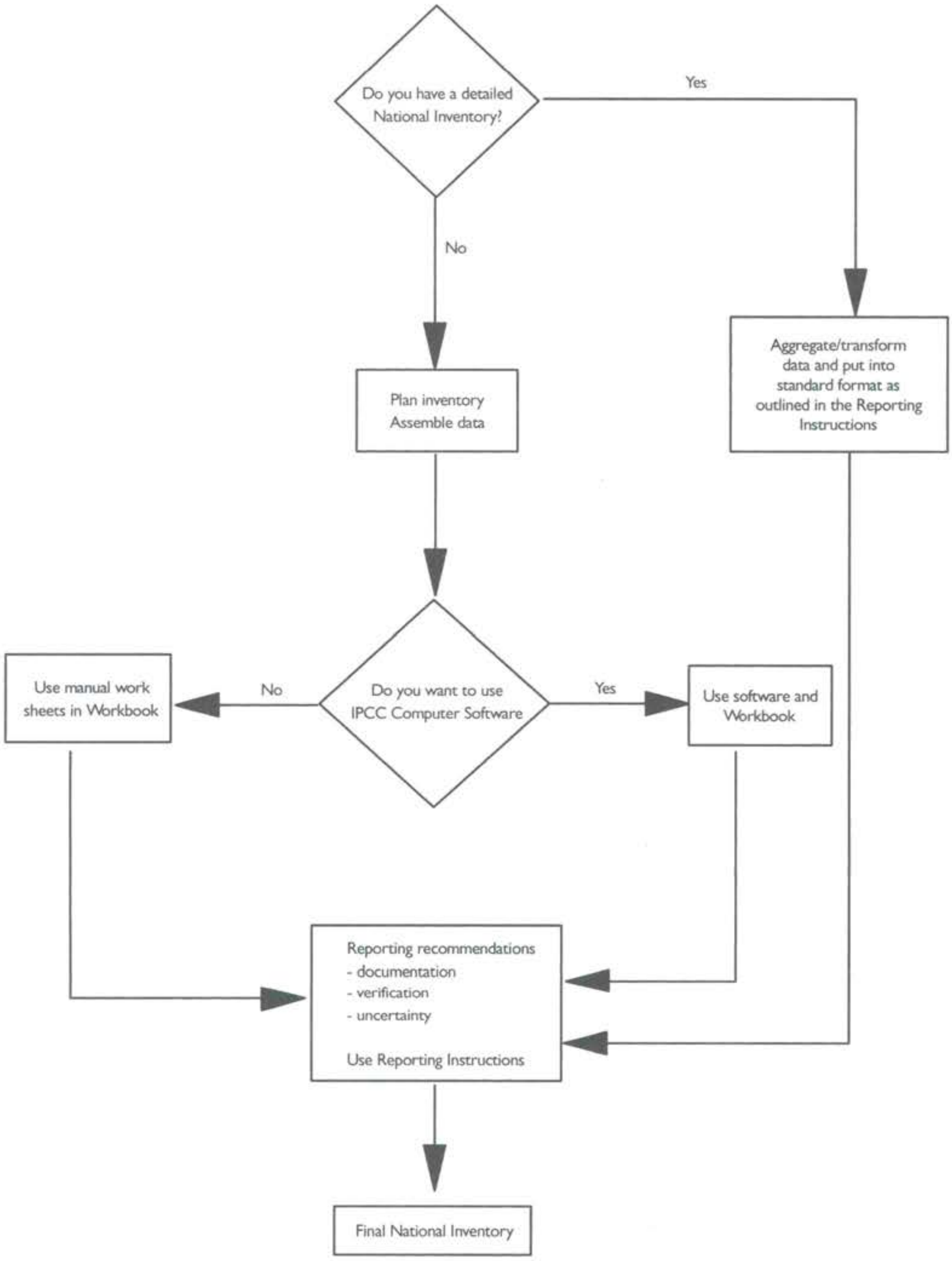
Module 6: Waste
- Land Disposal of Solid Waste
- Methane Emissions from Wastewater Treatment

Volume 3: Greenhouse Gas Inventory Reference Manual

Introduction to the Reference Manual
Chapter 1: Energy
Chapter 2: Industrial Processes
Chapter 3: Solvent and Other Product Use
Chapter 4: Agriculture
Chapter 5: Land Use Change & Forestry
Chapter 6: Waste

Before you start...

This diagram explains the stages needed to make a national inventory which meets IPCC standards.



The flow diagram above illustrates how the different types of users (working at different levels of inventory detail) can use the various volumes of the *Guidelines*. You should recognise that reality is more complex than this simple explanatory chart. Many countries may have some parts of the inventory complete at a high level of detail but may only be getting started on other parts. It is quite likely that some users will need to do several iterations of the thinking process reflected in the diagram with regard to different parts of their inventory.

The stages outlined in the flow diagram are:

Question 1
Do you have a detailed national inventory?

Answer: Yes

If your country already has a complete national inventory, you should transform the data it contains into a form suitable for use by IPCC. This means transforming it into a standard format. In order to do this, use Volume 1 of the *IPCC Guidelines*, *Reporting Instructions*. This gives details of the way in which data should be reported and documented.

Answer: No

You should start to plan your inventory and assemble the data you will need to complete the Worksheets in this book. Refer to the *Getting Started* section of the *Workbook*.

Question 2
Do you want to use the IPCC computer software?

Answer: Yes

If you want to use the IPCC software, you will still follow the instructions included in the *Workbook* to assemble the data you have collected into an inventory (see margin box). You will use the software instead of the printed worksheets to enter data.

Answer: No

If you do not use the IPCC software, use the *Workbook* and the Worksheets it contains to assemble the data you have collected into an inventory.

Finally...

Inventory data should be returned to IPCC in the form recommended in the *Reporting Instructions*. It is important that, where you have used a methodology other than the IPCC Default Methodology, it is properly documented. This will ensure that national inventories can be aggregated and compared in a systematic way in order to produce a coherent regional and global picture.

AVAILABILITY/USE OF COMPUTER SOFTWARE

IPCC computer software is available with the IPCC Guidelines. The software includes the same simple default methods as presented in the *Workbook* and the Standard Data Tables for reporting inventories, as presented in the *Reporting Instructions*. It is available in English only.

This version of the software should be run on a 386 based PC. The program requires a minimum of 570 kilobytes of free RAM and 2 Megabytes of EXTENDED RAM to run.

If you would like to receive a copy of the software, send a letter or fax to:

IPCC/OECD NATIONAL GHG INVENTORY PROGRAMME
Climate Change Division
OECD, Environment Directorate
2, rue André-Pascal
75775 PARIS CEDEX 16
FRANCE

FAX: (33-1) 45 24 78 76

General Notes on the Guidelines

Scope:

- The IPCC *Guidelines* are designed to estimate and report on national inventories of anthropogenic greenhouse gas emissions and removals. In general terms "anthropogenic" refers to greenhouse gas emissions and removals that are a direct result of human activities or are the result of natural processes that have been affected by human activities. Users may include any human-induced emissions and removals in their inventory as long as they can be clearly documented and quantified.

- National inventories should include greenhouse gas emissions and removals taking place within national (including administered) territories and offshore areas over which the country has jurisdiction. There are, however, four qualifications of this principle in the *Guidelines*:

  (a) Emissions based upon fuel sold to ships or aircraft engaged in **international** transport should, as far as possible, not be included in national totals but reported separately.

  (b) Emissions from road vehicles should be attributed to the country where the fuel is loaded into the vehicle. The error in national emissions introduced in the case of road transport is expected to be small.

  (c) Emissions from the combustion or decay of wood and wood products are assumed to take place in the country in which the wood was harvested and within a year of harvesting. This is because it has been determined that the most workable approach to estimating CO_2 emissions and removals from forests is to account for changes in stocks of standing biomass in forests and other locations. The simple assumption is that wood removed from stocks releases CO_2 emissions in the year and in the country where the wood was removed. While the IPCC method allows for accounting of exports and carbon stored in products, it does not yet provide a methodology, which is a priority for future work.

  (d) In line with the principle of national emissions, the IPCC methodology accounts for the bulk of greenhouse gas emissions related to fuel combustion in the country in which those emissions are released. The IPCC methodology for carbon stored in non-fuel products manufactured from fuels as raw materials takes into account emissions released from those products during their use or destruction. Emissions are attributed to the country where the conversion to non-energy products takes place, even when the products are traded internationally. This is believed to be a relatively small net error, but it is also a priority for future work.

Data Quality and Time Frame:

- The data available to estimate anthropogenic greenhouse gas emissions resulting from fuel combustion are generally of a better quality than the data available to estimate greenhouse gas emissions and removals in the areas of agriculture and land use change/forestry. Accordingly, while the IPCC *Guidelines* request an emission figure for a single year in most source/sink sectors, three-year averages (with the base year in the middle) are preferred in the areas of agriculture and land use change/forestry. In addition, the IPCC *Guidelines* recognise that greenhouse gas emissions and removals in the area of land use change/forestry can occur over an extended period of time once the activity has been completed. For example, when estimating emissions from the abandonment of forests and grasslands, users are requested to estimate emissions related to two time periods of previous activity: (a) 0 - 20 years ago, and (b) 20 - 100 years ago.

Default Method:

- The IPCC *Guidelines* contain "default" methodologies for the estimation of greenhouse gas emissions and removals. Users are encouraged to go beyond these minimum default methods where possible, and report the results.

  The IPCC *Guidelines* also include a number of "default" assumptions and data for use in the estimation of greenhouse gas emissions and removals. This default information is included primarily to provide users with a starting point from which they can develop their own national assumptions and data. Indeed, national assumptions and data are always preferred because the default assumptions and data may not always be appropriate for specific national contexts.

  In general, therefore, default assumptions and data should be used only when national assumptions and data are not available. Section 2 of the Introduction to the IPCC Greenhouse Gas Inventory *Workbook* provides information on the quality of the default data available in different greenhouse gas source/sink categories. When it is indicated that the data available are of low quality, users should recognise that the default data do not provide a basis for the development of a definitive inventory of that source/sink category.

- Many of the categories of greenhouse gas emissions and removals can be estimated only with large ranges of uncertainty. Quite naturally, some national experts have developed methods which are designed to produce ranges of estimates rather than point estimates for highly uncertain categories. The IPCC *Guidelines*, however, require that users provide a single point estimate for each gas and emissions/removal category. This is simply to make the task of compilation, comparison and evaluation of national reports manageable. Users are encouraged to provide uncertainty ranges or other statements of confidence or quality along with the point estimates. The procedures for reporting uncertainty information are discussed in the *Greenhouse Gas Inventory Reporting Instructions*.

Double Counting of Emissions:

The methods proposed for the estimation of emissions sometimes simplify the inventory construction in order to use data which are more readily available than those needed for a detailed and more precise approach. In certain cases this may cause or increase the risk of double counting emissions. There are two areas where this may occur in the *Guidelines*.

1) All countries preparing CO_2 inventories using the IPCC *Guidelines* are asked to estimate the emissions from fuel combustion using the IPCC Reference Approach either as the primary means of preparing the inventory or as a verification stage following the preparation of an inventory using national methods. The Reference Approach is a simple procedure which demands relatively little data and lends itself to wide-spread application as a "common denominator".

The Reference Approach provides an upper bound to CO_2 emissions inferred from the country's supply of fossil fuels by identifying the carbon content, subtracting from it the carbon stored in non-energy products and products made from fuels used as raw material, adjusting for carbon which remains unburnt and multiplying by 44/12. It is an upper bound[1] because some of the carbon will be emitted in forms other than CO_2, in part because fuel combustion is not always complete but also because fuels may leak or evaporate. Consequently the CO_2 emissions figure obtained from the Reference Approach will include carbon emitted as CH_4, CO or NMVOC. At the same time the *Guidelines* encourage countries to estimate separate inventories for these gases and when this is done these gases are reported twice, in their emitted form and as CO_2. It is in this sense that they are "double counted".

Use of the Reference Approach carries with it two consequences which should be carefully noted.

Because the Reference Approach uses fossil fuel supply statistics as a basis for determining the carbon supply

- Not all carbon based emissions from fossil fuel are reported twice. The Reference Approach CO_2 estimate will not include emissions from combustion or release of fossil fuels for which the corresponding quantities (activity data) are not included in national production or import figures. Notable examples of activities which lead to emissions not included are the venting of natural gases from coal mining and handling and oil and gas production. Emissions from the flaring of natural gases are also excluded. As a result, when emissions from these activities are included in the relevant inventories using the fugitive emissions methodologies recommended in the *Guidelines* no "double counting" occurs.

- CO_2 emissions from biomass used as fuels are excluded from the total CO_2 emissions figure. The restriction of the Reference Approach to fossil fuels results from the sustainable nature of biofuels. The CO_2 emissions are, however, reported for information purposes. Note that non-CO_2 emissions from biofuels are included in their respective inventories.

2) Double counting may also occur when *calculated* emissions from the manufacture of products from fuels used as raw materials or from the use of fuels for their physical properties (e.g. lubricants) include emissions produced from the later destruction of these products. The double count will be with any separate reporting within the Waste module of the *Guidelines* of emissions from destruction.

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[1] In practice, because of inaccuracies in the supply statistics and/or emission factors, CO_2 estimates from the Reference Approach may be less than those obtained by summing all CO_2 emissions from the combustion of fuel.

INTRODUCTION

INTRODUCTION TO THE WORKBOOK

1. Getting Started

Six gases are covered in the current version of the *Guidelines*. These are the direct greenhouse gases carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) and the indirect greenhouse gases carbon monoxide (CO), oxides of nitrogen (NO_x) and non-methane volatile organic compounds (NMVOCs). Other gases are being discussed and may be added in future versions of the *Guidelines*. Halogenated species (i.e. chlorofluorocarbons (CFCs), hydrochlorofluorocarbon 22 (HCFC-22), the halons, methyl chloroform and carbon tetrachloride) are not included because of parallel reporting requirements of countries in compliance with commitments under the Montreal Protocol.

Although estimation methods are not provided, countries are encouraged to report any emissions or removals for which they have data and which they consider significant to climate change. Procedures for reporting other gases are discussed in Volume 1 of the *Guidelines, Reporting Instructions*.

To estimate greenhouse gas emissions and removals you should begin by developing a plan or strategy. The first step is to identify the range of possible source and sink activities that exist in your country. Second, you will need to establish priorities for inventory work based on several considerations. One consideration is the priorities among various greenhouse gases. The IPCC has recommended the direct greenhouse gases CO_2, CH_4,as having highest priority. A second consideration is the relative importance of source and sink activities within the country and the availability of relevant information. Finally, once initial priorities have been developed, the analyst must identify and allocate resources to develop the inventory.

A description of greenhouse gas source and sink activities is provided in Volume I. The IPCC Scientific Assessment of 1990 and 1992 Supplement presents the current understanding of the contributions of various source and sink activities in the global atmospheric balances of CO_2, CH_4 and N_2O. This information is included here for consideration by national experts in prioritising national inventory efforts. Of course, the relative importance of source and sink categories for a specific country may be substantially different than at a global level.

Tables Introduction-1, Introduction-2 and Introduction-3 (below) summarise the global contributions:

TABLE INTRODUCTION-1 ESTIMATED BUDGET FOR CO_2 (Gt C PER YEAR) 1989/90		
Net Anthropogenic Sources	**Gt C/yr**	**Range (+/-)**
Fossil Fuel Combustion, Gas Flaring and Cement	6.0	0.5
Land Use Change and Deforestation	1.6	1.0
Total Net Sources	**7.6**	**1.5**
Natural		
Accumulation in the Atmosphere	(3.4)	(0.2)
Uptake by the Ocean	(2.0)	(0.8)
Terrestrial Sink	(1.0)	(1.0)
Total Accounted Carbon	**(6.4)**	**(1.0)**
Total Unaccounted Carbon ("missing sink")	**(1.2)**	**(0.5)**
Source: J.T. Houghton et. al., 1990 & 1992.		

TABLE INTRODUCTION-2 ESTIMATED BUDGET FOR METHANE (Tg CH_4 PER YEAR)		
Sources		
Natural	Tg CH_4/year	Range
• Wetlands	115	(100-200)
• Termites	20	(10-50)
• Ocean	10	(5-20)
• Freshwater	5	(1-25)
• CH_4 Hydrate	5	(0-5)
Anthropogenic		
• Coal Mining, Natural Gas and Petroleum Industry	100	(70-120)
• Rice Paddies	60	(20-150)
• Enteric Fermentation	80	(65-100)
• Animal Wastes	25	(20-30)
• Domestic Sewage Treatment	25	?
• Landfills	30	(20-70)
• Biomass burning	40	(20-80)
Sinks		
Atmospheric (tropospheric + stratospheric) removal	470	(450-520)
Removal by soils	30	(15-45)
Atmospheric Increase	32	(28-37)
Source: J.T. Houghton et. al., 1990 & 1992.		

Table Introduction-3 Estimated Budget for Nitrous Oxide (Tg N Per Year)	
Sources	
Natural	
Oceans	1.4 - 2.6
Tropical Soils	
Wet Forests	2.2 - 3.7
Dry Savannas	0.5 - 2.0
Temperate Soils	
Forests	0.05 - 2.0
Grasslands	
Anthropogenic	
Cultivated Soils	0.03 - 3.0
Biomass Burning	0.2 - 1.0
Stationary Combustion	0.1 - 0.3
Mobile Sources	0.2 - 0.6
Adipic Acid Production	0.4 - 0.6
Nitric Acid Production	0.1 - 0.3
Sinks	
Removal by Soils	?
Photolysis in the Stratosphere	7 - 13
Atmospheric Increase	3 - 4.5
Source: J.T. Houghton et. al., 1990 & 1992.	

The stages are:

Step 1 Planning the Inventory

1 Review *Reporting Instructions*

Review the *Reporting Instructions* (Volume 1 of IPCC *Guidelines*) so you know what data are required. Look in detail at Chapter 1: *Understanding the Common Reporting Framework*. This discusses standard definitions of pollutants, units, source/sink categories and time periods.

2 Identify priority sources/sinks and priority greenhouse gases. Ultimately, each country should report all important sources and sinks of all greenhouse gases. However, in practice, countries with little prior experience, which are getting started on national inventories, may wish to prioritise the possible gases and sources in terms of relative importance to global and national totals. Proceeding with highest priority sources first will reduce the initial burden on national experts and allow key results to be reported more quickly in international fora.

General priorities for countries preparing inventories are (listed in order of highest to lowest priority):

- CO_2 from Energy sources
- CO_2 from Land Use Change
- CH_4 from major source categories: Rice Production; Coal Mining; Oil and Natural Gas; Enteric Fermentation and Animal Waste; Landfills and Other Waste, and Biomass Burning
- Other greenhouse gases

This *Workbook* provides simple methods for all of the CO_2 and CH_4 categories listed above to help national experts in the high priority areas. Countries can modify the suggested priorities based on the importance of these source and sink activities in their own national context.

STEP 2 USING THE IPCC DEFAULT METHODS/DATA

The *Workbook* contains default methods for the estimation of each of the main source categories for CO_2 and CH_4. The *Reference Manual* contains background information on these methods and more detailed options. It also contains information on methods for N_2O and ozone precursors - CO, NO_x, and NMVOC. These methods are in various stages of testing and therefore are associated with different levels of confidence or "quality." IPCC's default methodology aims to provide the simplest realistic procedures for countries to use when making greenhouse gas emissions inventories. Default values are provided for emission factors and (some) activity data. Because default information is frequently general, and applicable to all countries of the world, it may not capture the variations in activities at the regional and national level that may significantly influence emission levels. The Workbook is nevertheless a starting point for many countries that are preparing inventories of CO_2 and CH_4 for the first time.

Countries may use more detailed methodologies, emission factors or activity data where these are compatible with IPCC source categories, and can be shown to give consistent and accurate results. Default emission factors and activity data also provide useful points of comparison for national assumptions. If a country's data vary significantly from the default data, the IPCC asks that the difference be explained. The tables in the next section *Data Availability and Quality* provide an overview of the availability and the quality of default data assumptions by major source category and gas. Some default information is found in the *Modules and Worksheets* part of this *Workbook*. Other country-specific default data are provided separately.

STEP 3 USING THE WORKBOOK

The *Workbook*

The *Workbook* is designed to be a working document. You use it as an integral part of making an inventory of your country's greenhouse gas emissions and removals. It is divided into six modules, each with its own icon:

- Energy
- Industrial Processes
- Solvent and Other Product Use

  [Solvent and Other Product Use is included in this version of the *Workbook* as a placeholder only. No simple estimation methods are provided for this category.]

- Agriculture
- Land Use Change and Forestry
- Waste

Within each module a series of emission sources are identified. Each emission source contains one (or more) Worksheets. These are blank forms for making the inventory which you fill in and return to IPCC.

To help you to use the Worksheets, each emission source section also contains:

- a brief introduction
- a survey of data sources
- an overview of the methodology recommended for the source
- instructions for completing the Worksheet

If you want to know more about a particular emission source, refer to the *IPCC Greenhouse Gas Inventory Reference Manual.*

STEP 4 PROVIDING DOCUMENTATION

In every case written documentation should be provided along with inventory results explaining the sources of any input data which were not taken from the default data included in the *Workbook*. For example, energy related GHG input data includes energy data, conversion factors, emission factors, production data for products which store carbon and any other information which might affect the results in the inventory.

Preferably your documentation should cite published reports as the source of data. Government ministries, institutes or private firms that have provided data should be identified by a mailing address and a contact person. See Volume 1: *Reporting Instructions* for details of documentation requirements.

STEP 5 REPORTING FINER LEVELS OF DETAIL IN THE WORKSHEETS

For simplicity and clarity, the *Workbook* deals with calculation of emissions at a national level, with source categories broken down into relatively few subcategories. The level of detail in the subcategories is designed to match the available sources of default input data, carbon contents and other assumptions. However, as a user of the emissions methodology *Guidelines,* you are encouraged to carry out your national inventory at as fine a level of detail as possible. If your country has more detailed information on any of the source categories than that used in constructing the default values in this *Workbook*, you are encouraged to use it.

There are two ways in which this is possible:

- Finer geographic detail

  Experts may find that it is necessary to divide a country into different regions to capture differences between ecosystems and biomass densities, agricultural practices, rates of burning etc.

- Finer detail by subcategory

  Where data are available, experts may subdivide the categories of activity to reflect important differences in economic activity, ecology or species, land use or agricultural practices, rate of burning, etc.

Working at a finer level of disaggregation does not change the nature of the calculations although more locally developed data and assumptions will generally be required. Use multiple copies of the Worksheets for these calculations.

If you have calculated greenhouse gas emissions at a finer level of detail, you should also aggregate results up to the most detailed level of information requested by the IPCC methodology in order to report them. This allows comparisons to be made among the results from countries participating in the inventory. You are also encouraged to report at the underlying level of detail if it is manageable.

Make sure that you report data and assumptions to the IPCC in order to ensure transparency and replicability of methods. *Reporting Instructions* (Volume 1 of the *Guidelines*) discusses these issues in more detail.

2 Data availability and Quality

The tables on the following pages provide a summary of the types of activity data, emission factors and other data needed to carry out the simplest, default calculations of emissions of CO_2, CH_4, and N_2O. They also indicate the data which are included in the *Workbook* or are readily available from international sources, and provide indicators of the quality of available default data. These indicators reflect the judgement of the IPCC/OECD programme technical staff regarding the likely technical accuracy or quality of default data or emission factors in the context of a national emissions/removals estimate. The differences reflect:

- The variations in availability and quality of international compilations of data on the different categories of human activity which cause emissions.
- The representativeness of available global or regional default emission factors when used at national level.
- Variations in the level of scientific understanding of the various human induced phenomena which cause greenhouse gas emissions.

This information may be used by national experts to prioritise their efforts to obtain and use more detailed national data, and assessing the quality of any estimates produced.

Other gases

The IPCC *Guidelines* also include, where possible, emission estimation methods and reporting formats for carbon monoxide (CO), nitrogen oxides (NO_x) and non-methane volatile organic compounds (NMVOCs); these gases contribute to the atmospheric formation of ozone. The lower priority attributed to these gases in the first phase of the *Guidelines* preparation results from their "indirect" greenhouse effect and the relative wealth of research results assembled in the sources listed below. Some of this material has been included within the *Guidelines.* Users are encouraged to prepare inventories for these gases using the *Guidelines* and drawing on the original material contained in the references.

European Environment Agency Taskforce (EEATF) (1992), *Default Emission Factor Handbook.*

US EPA, (1986). *Compilation of Air Pollution Emissions Factors, Vol. 1: Stationary Point and Area Sources,* AP.42, Supplement A.

S.D. Piccot, A. Chadha, J. De Waters, T. Lynch, P. Marsosudiro, W. Tax, S. Walata, and J.D. Winkler (1990), *Evaluation of Significant Anthropogenic Sources of Radiatively Important Trace Gases.* Prepared for the Office of Research and Development, US EPA Washington D.C., US.

2.1 Energy

Source Categories	Priority Gases	Availability and Quality of Data and Methods	
1A FUEL COMBUSTION ACTIVITIES	CO_2	Activity Data	Fuel consumption by detailed fuel subcategory. - Provided by IEA (1992) and UN (1992a) (H-M)*
		EF and related data.	C emission factors, and country-specific net calorific values (heat content); (H-M)*
1A1-2 & 1A4-6	CH_4, N_2O	Activity Data	Fuel consumption must be allocated to specific end-use subsectors and technology or process types to estimate these gases. IEA (1992) or UN (1992a) data provide control totals but no international data are available at the process/technology level (NP).
	CH_4	EF	Summarised in *Reference Manual* (M)
	N_2O	EF	Summarised in *Reference Manual* (L).
1A3 TRANSPORT	CH_4, N_2O	Activity Data	Fuel combustion by vehicle type with fleet profiles, driving characteristics, technology. No international data sources. (NP)
	CH_4	EF	Summarised in *Reference Manual* (M)
	N_2O	EF	Summarised in *Reference Manual* (L).
1B FUGITIVE EMISSIONS FROM FUELS			
1B1 SOLID FUELS	CH_4	Activity Data	Underground and surface coal production available from IEA (1992) and UN (1992) (H-M).
		EF	Global average range provided. Large uncertainty at country level. (L)
	CO_2	Activity Data & EF	(NP)
1B2 OIL AND NATURAL GAS	CH_4 CO_2	Activity Data	Oil/Gas production and consumption, oil loaded on tankers (exports) IEA (1992) and UN (1992) (H-M)* Number of wells drilled; no default data.
	CH_4	EF	Regional ranges provided. Large uncertainty at country level.
	CO_2	EF	(NP)

* In general these default data are quite good and should produce high quality estimates at the country level. There may be a few countries for which data have not been recently and carefully reported or which have unusual fuel characteristics. For these countries, application of default data may produce emission estimates of only moderate quality.

Key to abbreviations:

GHG - Greenhouse Gas

EF - Emission Factor

H - High Quality

M - Medium Quality

L - Low Quality

NAV - Not Available

NP - Not Provided

2.2 Industrial Processes

SOURCE CATEGORIES	PRIORITY GASES	AVAILABILITY AND QUALITY OF DATA AND METHODS	
2A IRON AND STEEL	CO_2, CH_4 N_2O	Activity Data	Available from UN (1992b) (M)
	CH_4	EF	(NP)
	CO_2, N_2O	EF	(NP)
2B NON-FERROUS METALS	CO_2, N_2O	Activity Data & EF	(NP)
2C INORGANIC CHEMICALS	N_2O	Activity Data	Nitric acid production from UN (1992b) (M)
		EF	*Reference Manual* (L)
2D ORGANIC CHEMICALS	CH_4, N_2O	Activity Data	Production of specific chemicals including adipic acid, from UN (1992b) (M)
		EF	*Reference Manual* - global average (L)
2E NON-METALLIC MINERALS	CO_2	Activity Data	Production of specific products from UN (1992b) (M) US Bureau of Mines (1992)
		EF	*Reference Manual* for cement (M). Other products (NP)
2F OTHER	CO_2, CH_4, N_2O	Activity Data & EF	(NP)

2.3 Solvent and Other Product Use

[Not treated in this version of the *Workbook*]

KEY TO ABBREVIATIONS:

GHG - Greenhouse Gas

EF - Emission Factor

H - High Quality

M - Medium Quality

L - Low Quality

NAV - Not Available

NP - Not Provided

2.4 Agriculture

SOURCE CATEGORIES	PRIORITY GASES	AVAILABILITY AND QUALITY OF DATA AND METHODS	
4A ENTERIC FERMENTATION	CH_4	Activity Data	International data on number of animals by country (FAO, 1991a)(H-M).
		Other Related Data	Average weight by animal type, feed intake & type of feed (NP).
		EF	Provided in the *Workbook* and *Reference Manual* (M) need testing in countries outside of OECD.
4B MANURE MANAGEMENT	CH_4	Activity Data	International data on number of animals by country FAO (1991a) (H-M).
		Other Related Data	- waste production per animal per day - % volatile solids in waste - methane emission potential in volatile solids - fraction of methane potential realised - type of waste storage system (NP).
		EF	Default factors provided for variables identified above but assumptions (and method) not yet extensively tested. (M-L)
4C RICE CULTIVATION	CH_4	Activity Data	International data on number of hectare days cultivated annually, (Matthews et al) FAO (1991a) (M)
		Other Related Data	Irrigation regime, temperature.(M-L)
		EF	Limited testing, some important parameters not yet included. (M-L)
4D AGRICULTURAL SOILS (Reference Manual)	N_2O	Activity Data	Nitrogen fertiliser sales per country per year (FAO, 1991b) (NP) Organic nitrogen applied, biological fixation (NP)
		Other Related Data	Soil temperature, moisture content, nitrogen content, atmospheric deposition and others not yet included in method. (NP)
		EF	(NP)
4E PRESCRIBED BURNING OF SAVANNAS	CH_4, N_2O	Activity Data	Savanna area FAO (1993) (H-M) Crude rules of thumb provided for fraction burned, other biomass characteristics (L)
		Other GHG EF	Defaults provided (L)
4F FIELD BURNING OF AGRICULTURAL RESIDUES	CH_4, N_2O	Activity Data	Production by crop FAO (1991a) (H-M) Residue, crop ratios etc. (M-L). Fraction burned in fields (NP)
		Other GHG EF	Defaults provided (L)

KEY TO ABBREVIATIONS:

GHG - Greenhouse Gas
EF - Emission Factor
H - High Quality
M - Medium Quality
L - Low Quality
NAV - Not Available
NP - Not Provided

2.5 Land Use Change & Forestry

SOURCE CATEGORIES	PRIORITY GASES	AVAILABILITY AND QUALITY OF DATA AND METHODS	
5A CHANGES IN FOREST AND OTHER WOODY BIOMASS STOCKS	CO_2	Activity Data	NP FAO Assessments (1993) (L)
		EF	Regional defaults high uncertainty (L),.
5B FOREST AND GRASSLAND CONVERSION	CO_2 and Other GHG	Activity Data	- quantity of biomass burned - biomass/soil carbon content - % biomass/soil carbon released as CO_2 - nitrogen/carbon ratio of biomass - trace gas emissions ratios. FAO Assessments (1993) (L)
		EF	Regional defaults high uncertainty (L), limited testing
5C ABANDONMENT OF MANAGED LANDS	CO_2	Activity Data	NP
		EF	Regional defaults high uncertainty (L)

KEY TO ABBREVIATIONS:

GHG - Greenhouse Gas

EF - Emission Factor

H - High Quality

M - Medium Quality

L - Low Quality

NAV - Not Available

NP - Not Provided

2.6 Waste

SOURCE CATEGORIES	PRIORITY GASES	AVAILABILITY AND QUALITY OF DATA AND METHODS	
6 A SOLID WASTE DISPOSAL ON LAND	CH_4, CO_2	Activity data	International data on waste quantities produced by country can be derived from population data - UN (1991b), OECD (1992), Piccot et al 1990 (L).
		Other Related Data	- % of total waste landfilled - % of degradable organic carbon (DOC) - % of carbon dissimilated - % CH_4 in total biogas (NP).
		EF	Based on above data. (L)
6 B WASTEWATER TREATMENT	CH_4, N_2O	Activity Data	BOD of wastewater can be derived from population and industrial production data - UN (1991b) and crude rules of thumb (L)
	CH_4	EF	(L)
	N_2O	EF	(NP)
6 C WASTE INCINERATION (Reference Manual)			No default method (NP)

KEY TO ABBREVIATIONS:

GHG - Greenhouse Gas

EF - Emission Factor

H - High Quality

M - Medium Quality

L - Low Quality

NAV - Not Available

NP - Not Provided

3 Basic Information to Help Work with the IPCC Guidelines

Prefixes and multiplication factors

The following multiplication factors are used throughout the *Guidelines*:

Multiplication Factor	Abbreviation	Prefix	Symbol
1 000 000 000 000 000	10^{15}	peta	P
1 000 000 000 000	10^{12}	tera	T
1 000 000 000	10^{9}	giga	G
1 000 000	10^{6}	mega	M
1 000	10^{3}	kilo	k
100	10^{2}	hecto	h
10	10^{1}	deca	da
0.1	10^{-1}	deci	d
0.01	10^{-2}	centi	c
0.001	10^{-3}	milli	m
0.000 001	10^{-6}	micro	μ

Abbreviations for chemical compounds

The following abbreviations are used in the *Guidelines*:

CH_4	Methane
N_2O	Nitrous Oxide
CO_2	Carbon Dioxide
CO	Carbon Monoxide
NO_x	Nitrogen Oxides
NMVOC	Non-Methane Volatile Organic Compound
NH_3	Ammonia
CFCs	Chlorofluorocarbons
HFCs	Hydrofluorocarbons
PFCs	Perfluorocarbons
SF_6	Sulphur hexafluoride
CCL_4	Carbon tetrachloride
C_2F_6	Hexafluoroethane

Standard equivalents

1 tonne of oil equivalent (toe)	1 x 10^{10} calories
10^3 toe	41.868 TJ
1 short ton	0.9072 tonne
1 tonne	1.1023 short tons
1 tonne	1 megagram
1 kilotonne	1 gigagram
1 megatonne	1 teragram
1 kilogram	2.2046 lbs
1 hectare	10^4 m^2
1 calorie $_{IT}$	4.1868 Joules
1 atmosphere	101.325 kPa

Units[1] and abbreviations

The following abbreviations are used in the *Guidelines*:

cubic metre	m^3
hectare	ha
gram	g
tonne	t
joule	J
degree Celsius	°C
calorie	cal
year	yr
capita	cap
gallon	gal
dry matter	dm

[1] For decimal prefixes see previous page.

4 References - Major Sources of Activity Data

FAO (Food and Agriculture Organization of the United Nations) (1991*a*), *Production Yearbook*, FAO, Rome, Italy (annual).

FAO (Food and Agriculture Organization) (1991*b*), *FAO 1991 Fertilizer Yearbook*, FAO, Rome, Italy (annual).

FAO (Food and Agriculture Organization) (1993), *Forest Resources in the Tropical World*, FAO, Rome, Italy (annual).

Griffin, R.C., (1987), "CO_2 release from cement production, 1950-1985". In Marland, G., T.A. Boden, R.C. Griffin, S.F. Huang, P. Kanciruk and T.R. Nelson. *Estimates of CO_2 Emissions from Fossil Fuel Burning and Cement Manufacturing, Based on the United Nations Energy Statistics and the US Bureau of Mines Cement Manufacturing Data*. Report N° ORNL/CDIAC-25, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee, US, May 1989, pp. 643-680.

Houghton, J.T., G.J. Jenkins and J.J. Ephramus (1990), *Climate Change: The IPCC Assessment*, Cambridge U. Press, Cambridge, UK.

Houghton, J.T., B.A. Callander and S.K. Varney (1992), *Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment*, Cambridge U. Press, Cambridge, UK.

IEA (International Energy Agency) (1992), *Energy Balances in OECD Countries*, and *Energy Statistics and Balances of Non-OECD Countries*, Paris, France (annual).

Matthews, E., I. Fung and J. Lerner (1991), "Methane emission from rice cultivation: Geographic and seasonal distribution of cultivated areas and emissions". *Global Biogeochemical Cycles* 5:3-24.

OECD (Organisation for Economic Co-operation and Development/ International Energy Agency) (1992), *Environmental Data Compendium* , OECD/IEA, Paris, France (annual).

Piccot, S.D., A. Chadha, J. DeWaters, T. Lynch, P. Marsosudiro, W. Tax, S. Walata and J.D. Winkler, (1990), *Evaluation of Significant Anthropogenic Sources of Radiatively Important Trace Gases*. Prepared for the Office of Research and Development, US EPA Washington D.C., US.

United Nations (1992*a*), *Energy Statistics Yearbook*, United Nations, New York, US (annual).

United Nations (1992*b*), *United Nations Statistical Yearbook*, United Nations, New York, US (annual).

US Bureau of the Mines (1988), *Cement Minerals Yearbook*, by Wilton Johnson, US Bureau of Mines, US Department of the Interior, Washington D.C., US (annual).

References used in developing emission factors and other default values used in the *Workbook* are discussed in the relevant sections of the *Greenhouse Gas Inventory Reference Manual.*

MODULE I
ENERGY

ENERGY

1 ENERGY

1.1 Introduction

This module gives instructions for estimating the emissions of greenhouse gases from energy activities. It is divided into two categories each with two subcategories:

- Combustion
  - CO_2 from Energy: Reference Approach
  - Greenhouse Gas Emissions from Burning Traditional Biomass Fuels
- Fugitive
  - Methane Emissions from Coal Mining and Handling Activities
  - Methane Emissions from Oil and Natural Gas Activities

COMBUSTION

1.2 CO_2 From Energy: Reference Approach

Introduction

Carbon dioxide emissions are produced when carbon-based fuels are burned. National emissions estimates are made based on amounts of fuels used and the carbon content of fuels.

Fuel combustion is widely dispersed throughout most activities in national economies and a complete record of the quantities of each fuel type consumed in each "end use" activity is a considerable task, which some countries have not undertaken. Fortunately, it is possible to obtain an accurate estimate of national CO_2 emissions by accounting for the carbon in fuels supplied to the economy. The supply of fuels is simple to record and the statistics are more likely to be available in many countries.

In accounting for fuels supplied it is important to distinguish between *primary fuels* (i.e. fuels which are found in nature such as coal, crude oil, natural gas), and *secondary fuels* or fuel products, such as gasoline and lubricants, which are derived from primary fuels.

Accounting for carbon is based mainly on the supply of primary fuels and the net quantities of secondary fuels brought into the country.

To calculate supply of fuels to the country you require the following data for each fuel and year chosen:

- the amounts of primary fuels produced (production of secondary fuels is excluded)
- the amounts of primary and secondary fuels imported
- the amounts of primary and secondary fuels exported
- the amounts of fuel used for international marine and aviation bunkers
- the net increases or decreases in stocks of the fuels

For each fuel, the production (where appropriate) and imports are added together and the exports, bunkers, and stock changes are subtracted to calculate the apparent consumption of the fuels.

The manufacture of secondary fuels should be ignored in the main calculation, as the carbon in these fuels has already been accounted for in the supply of primary fuels from which they are derived. However, information on production of some secondary fuel products is required to adjust for carbon stored in these products.

The procedure calculates the supply of primary fuels to the economy with adjustments for net imports (imports - exports), bunkers and stock changes in secondary fuels. It is important to note that, in cases where exports of secondary fuels exceed imports or stock increases exceed net imports, negative numbers will result. This is correct, and should not give rise to concern.

Three other important points influence the accounting methodology:

- *Stored carbon*

  Not all fuel supplied to an economy is burned for heat energy. Some is used as a raw material (or feedstock) for manufacture of products such as plastics or in a non-energy use (e.g. bitumen for road construction), without oxidation (emissions) of the carbon. This is called *stored carbon*, and is deducted from the carbon emissions calculation. Estimation of the stored carbon requires data for fuel use by activities using the fuel as raw material. These requirements are explained later.

- *International Bunker fuels*

  The procedures given for calculating emissions ensure that emissions from the use of fuels for international marine and air transport are excluded from national emissions totals. However, for information purposes, the quantities and types of fuels delivered for international marine and aviation bunkers and the emissions should be separately reported.

- *Biomass fuels*

  Biomass fuels are included in the national energy and CO_2 emissions accounts for information only. Within the energy module biomass consumption is assumed to equal its regrowth. Any departures from this hypothesis are counted within the Land use change and Forestry module.

Data Sources

Locally available data should be used wherever possible. Energy data for a large number of countries are also published by the International Energy Agency and the United Nations Statistical Division. See *Reference Manual* Chapter 1, Section 1-3.

In addition to energy data, default emissions factors, and other input assumptions, are provided in the *Workbook* where available. In calculating national emissions, users of this method are free to override any of these assumptions or recommendations if other information is preferred. Wherever information is used other than the values recommended in the *Workbook*, this should be noted and documentation should be provided on the sources of the information.

Methodology

The IPCC methodology breaks the calculation of carbon dioxide emissions from fuel combustion into 6 steps:

Step 1: Estimate Apparent Fuel Consumption in Original Units

Step 2: Convert to a Common Energy Unit

Step 3: Multiply by Emission Factors to Compute the Carbon Content

Step 4: Compute Carbon Stored

Step 5: Correct for Incomplete Combustion

Step 6: Convert Carbon Oxidised to CO_2 Emissions

Completing the Worksheet

Use WORKSHEET 1-1: CO_2 FROM ENERGY SOURCES (REFERENCE APPROACH) and AUXILIARY WORKSHEET 1-1: ESTIMATING CARBON STORED IN PRODUCTS at the end of this module to enter the data for this submodule.

This section provides step-by-step instructions for calculating emissions at the detailed fuels and fuel products level.

Note that the main worksheet allows CO_2 emissions from biomass fuels to be calculated but it does not include them in the national total.

In general, international energy statistics are consistent with this level of detail, but locally available data may be used.

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary.

STEP 1 ESTIMATING APPARENT FUEL CONSUMPTION

IEA DATA

National data reported to and collected by the International Energy Agency (IEA) are provided as default data if you wish.

EXPORT DATA

In some data sources, Exports are shown as a negative number. For this method, all Export data should be entered as positive.

BUNKER FUEL

Where indicated in Worksheet 1-1, (sheet 1), enter the amount of a particular fuel consumed as international bunker fuel (fuel used in international marine and aviation transportation). The calculation of Apparent Consumption automatically excludes these quantities. Bunker consumption data and related emissions are listed separately in Worksheet 1-1, sheets 4 and 5, and follow the main steps as in the main Worksheet.

STOCK CHANGE DATA

An increase in stock is a positive stock change and, since it is subtracted, will decrease Apparent Consumption; a stock reduction (use of fuel from existing stocks) is a negative value and will increase Apparent Consumption.

1 Apparent consumption is the basis for calculating the carbon supply to the country. To calculate apparent consumption (or total fuel supplied) for each fuel, enter the following data for primary fuels.

- Production (column A)
- Imports (column B)
- Exports (column C)
- International Bunkers (column D)
- Stock Change (column E)

For secondary fuels and products, the only figures to be entered are:

- Imports (column B)
- Exports (column C)
- International Bunkers (column D)
- Stock Change (column E)

These allow the overall calculation to account for all consumption.

Amounts of all fuels can be expressed in joules (J), megajoules (MJ), gigajoules (GJ), terajoules (TJ), thousands of tonnes of oil equivalent (ktoe). Solid or liquid fuels can be expressed as thousands of tonnes (kt) and dry natural gas can be expressed as teracalories (Tcal).

Note that the figure for production of natural gas, used in the Worksheet 1-1, must **not** include quantities of gas vented, flared or re-injected into the well.

If you report quantities of fuel expressed in energy units (terajoules, toe, etc.), you should ensure that the quantities have been calculated using the net calorific values (NCV) of the fuels concerned. NCV is sometimes referred to as the lower heating value (LHV). NCVs are approximately 95 per cent of the gross calorific value (GCV) for liquid fossil, solid fossil and biomass fuels, and 90 per cent of the GCV for gaseous primary fuels. Default energy data are provided in NCV. For other sources, you should determine if the figures have been derived using the net or gross calorific values and make the conversion to NCV if necessary.

2 When you have entered data in columns A to E, calculate Apparent Consumption for each fuel using this formula:

Apparent Consumption = Production + Imports - Exports - International Bunkers - Stock Change

Enter the result in column F.

Particular attention should be given to the algebraic sign of "stock change" as it is entered in column E. When more fuel is added to stock than is taken from it during the year there is a net stock build and the quantity is entered in column E with a plus sign. In the converse case (a stock draw) the quantity should be entered in column E with a minus sign. When calculating Apparent Consumption using the above formula the usual algebraic rules for combining signs should be used.

STEP 2 CONVERTING TO A COMMON ENERGY UNIT (TJ)

TABLE 1-1
CONVERSION FACTORS

UNIT	CONVERSION FACTOR
J, MJ or GJ	Divide by the appropriate factor, 10^{12}, 10^6 or 10^3 respectively, to convert to TJ.
10^6 toe units	Multiply by the conversion factor, 41868 TJ/10^6 toe, to convert to TJ
Tcal units	Multiply by the conversion factor, 4.1868 TJ/Tcal.
10^3 t	The Net Calorific Value of each fuel should be used. See box entitled "Net Calorific Values".

NOTE: When converting from 10^3 t, for Anthracite, Coking Coal, other Bituminous Coal, Sub-bituminous Coal and Lignite, separately shown *Country Specific Conversion Factors* in the Reference Manual provide different conversion values for Production (column A), Imports (column B), and Exports (column C). For these fuels, the user should calculate Apparent Consumption by converting Production, Imports, Exports, and Stock Changes to TJ first. For International Bunkers (column D) and Stock Change (column E), use either a weighted average conversion factor or select a factor appropriate to the dominant source of supply.

1 Enter the conversion factor used for each fuel in column G.

Tables 1-2 and 1-3 and other tables provided in the *Reference Manual* show conversion factors.

2 Multiply the Apparent Consumption by the relevant Conversion Factor (NCV or scaling factor) to give Apparent Consumption in terajoules. Enter the result in column H.

NET CALORIFIC VALUES (NCV)

The calorific value of a fuel is a measure of its value for heating purposes. If NCVs are available for the fuels in your country, they should be used. Default NCVs for oil and coal products for many countries are provided in the *Reference Manual* (Volume 3). If NCVs for your country are not provided, select NCVs for a country that uses fuels similar to those used in your country.

NCVs for Refined Petroleum Products and some other products are shown in Table 1-3.

In all cases, you should report the conversion factors which you have used in column G. If you use values other than those provided, please include a note explaining the source of the factors.

TABLE 1-2 CARBON EMISSION FACTORS (CEF)	
Fuel	Carbon Emission Factor (t C/TJ)
LIQUID FOSSIL	
Primary fuels	
Crude oil	20.0
Natural Gas Liquids	17.2
Secondary fuels/products	
Gasoline	18.9
Jet Kerosene	19.5
Other Kerosene	19.6
Gas/Diesel Oil	20.2
Residual Fuel Oil	21.1
LPG	17.2
Ethane	16.8
Naphtha	(20.0) [1]
Bitumen	22.0
Lubricants	(20.0) [1]
Petroleum Coke	27.5
Refinery Feedstocks	(20.0) [1]
Other Oil	(20.0) [1]
SOLID FOSSIL	
Primary Fuels	
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/Products	
BKB & Patent Fuel	(25.8) [1]
Coke	29.5
GASEOUS FOSSIL	
Natural Gas (Dry)	15.3
BIOMASS	
Solid Biomass	29.9
Liquid Biomass	(20.0) [1]
Gas Biomass	(30.6) [1]

[1] This value is a default value until a fuel specific CEF is determined. For Gas biomass, the CEF is based on the assumption that 50% of the carbon in the biomass is converted to methane and 50% is emitted as CO_2. The CO_2 emissions from biogas should not be included in national inventories. If biogas is released and not combusted 50% of the carbon content should be included as methane.

TABLE 1-3 SELECTED NET CALORIFIC VALUES	
	Factors (TJ/10^3 tonnes)
Refined Petroleum Products	
Gasoline	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
Other Products	
Coal Oils and Tars derived from Coking Coals	28.00
See the *Greenhouse Gas Inventory Reference Manual* for sources.	

STEP 3 MULTIPLYING BY CARBON EMISSION FACTORS

1 Enter the Carbon Emission Factor (CEF) which you are using to convert Apparent Consumption into Carbon Content in column I.

Table 1-2 shows default values which you can use if there are no locally available data.

2 Multiply the Apparent Consumption in TJ (in column H) by the Carbon Emission Factor (in column I) to give the Carbon Content in tonnes of C. Enter the result in column J.

4 Divide Carbon Content in tonnes C by 10^3 to give gigagrams of Carbon. Enter the result in column K.

5 Calculate subtotals for Liquid, Solid, Gaseous, and Biomass Fuel categories, then add the subtotals for Solid Fossil, Liquid Fossil, and Gaseous Fossil Fuels to give the Total figure (column K). This is for information purposes only.

STEP 4 CALCULATING CARBON STORED

Data, additional to those needed for calculating Apparent Consumption, are needed for this step (see box). Use AUXILIARY WORKSHEET 1-1: ESTIMATING CARBON STORED IN PRODUCTS.

1 Estimating Fuel Quantities

Bitumen and lubricants

Add Domestic Production for Bitumen and Lubricants to the Apparent Consumption (shown in column F of the main Worksheet 1-1) for these products and enter the sum in column A of the Auxiliary Worksheet 1-1.

Coal oils and tars

For coking coal, the default assumption is that 6 per cent of the carbon in coking coal consumed is converted to oils and tars. Multiply the Apparent Consumption for coking coal (from Worksheet 1-1, column F) by 0.06. If better information on production of coal oils and tars is locally available, this should be used and the source of the data noted. Enter the result in column A.

Natural gas, LPG, Naphtha and Gas/Diesel oil

Estimate the amount of these fuels that is used as a feedstock for non-energy purposes and enter it in column A.

2 Converting to TJ

Insert the appropriate Conversion Factors in column B. Multiply Estimated Fuel Quantities (column A) by the relevant Conversion Factor to give the Estimated Fuel Quantities in TJ. Enter the result in column C of the Auxiliary Worksheet 1-1.

3 Calculating Carbon Content

Multiply the Estimated Fuel Quantities in TJ (column C) by the Emission Factor (in tonnes of carbon per terajoule) (column D) to give the Carbon Content in tonnes C (column E). Divide the figures by 10^3 to express the amount as gigagrams of carbon. Enter the results in column F of the Auxiliary Worksheet 1-1.

4 Calculating Actual Carbon Stored

Multiply the Carbon Content (column F) by the Fraction of Carbon Stored (column G) to give the Carbon Stored. Enter the result in column H of the Auxiliary Worksheet 1-1.

When you have completed the Auxiliary Worksheet 1-1

5 Enter values for Carbon Stored for the relevant fuels/products in column L of the main Worksheet 1-1.

6 Subtract the values for Carbon Stored (column L) from Carbon Content (column K) to give Net Carbon Emissions. Enter the results in column M.

CALCULATING CARBON STORED

To calculate carbon stored, it is necessary to work at a more detailed fuel product level. In order to carry out this calculation, the user will have to provide some additional information. If this information is not available or considered credible, you may choose not to calculate stored carbon. This should be noted in the documentation of the submitted results.

Use the Auxiliary Worksheet 1-1 at the end of this section for your calculations. The majority of stored carbon is accounted for using this list of fuels, but countries are encouraged to report carbon stored for any other fuels for which they have data.

IF YOU DO NOT WISH TO CALCULATE STORED CARBON

Skip step four, enter the values from column K in column M of Worksheet 1-1, and continue with step 5.

TABLE 1-4 FRACTION OF CARBON OXIDISED	
Coal[1]	0.98
Oil and Oil products	0.99
Gas	0.995
Peat for electricity generation[2]	0.99

1 This figure is a global average but varies for different types of coal, and can be as low as 0.9.

2 The fraction for peat used in households may be much lower.

STEP 5 CORRECTING FOR INCOMPLETE COMBUSTION

1 Enter values for Fraction of Carbon Oxidised in column N of the Worksheet 1-1. Table 1.4 provides information on typical values measured from coal facilities and suggests global default values for solid, liquid and gaseous fuels. If more specific information is locally available, this should be used and documented.

2 Multiply Net Carbon Emissions (column M) by Fraction of Carbon Oxidised (column N) and enter the result in column O, Actual Carbon Emissions.

STEP 6 CONVERTING TO CO_2 EMISSIONS

1 Multiply Actual Carbon Emissions (column O) by 44/12 to find Total Carbon Dioxide (CO_2) emitted from fuel combustion. Enter the results in column P.

2 The sum is total national emissions of carbon dioxide from fuel combustion.

1.3 Greenhouse Gas Emissions from Burning Traditional Biomass Fuels

Introduction

Emissions of Other Gases from Biomass Fuel Combustion

Unlike CO_2 emissions from biomass used for fuel, which are considered zero on a net basis, emissions of methane, carbon monoxide, nitrous oxide and nitrogen oxides should be included in the energy sector emission inventories. These emissions occur in all small-scale burning of biomass fuels, such as cooking stoves and open fires, and also during the production of charcoal. The method used for their estimation is based upon the carbon released at the point of combustion and a number of trace gas ratios relating the mass of trace gas released to the amount of carbon released.

Data Sources

The main data required to perform these calculations are estimates of the mass of biomass fuels consumed by type of fuels. These data, if not available, can be estimated from population statistics.

- FAO Forest Products Yearbooks.
- FAO Forest Resources Assessment 1990: Tropical Countries. Rome 1993.
- IEA and UN Energy Data

More detailed discussion of data is provided in the *Reference Manual.*

Methodology

There are two stages to the calculation.

First, estimate the amount of carbon released to the atmosphere in order to derive non-CO_2 trace gas emissions. The activity data required are the consumption of various types of biomass fuels. Based on the type of fuel burned, the carbon content of the biomass fuel and the fraction oxidised, the amount of carbon released can be calculated.

Second, emission ratios are applied to estimate the amount of non-CO_2 trace gas released in relation to the amount of carbon released.

Tables 1-5 and 1-6 provide default data for key variables.

Completing the Worksheets

There are two worksheets in this submodule. Worksheet (1-2) is optional. You should use it if your country does not possess statistics for the consumption of traditional biomass fuels as Worksheet 1-3 requires these quantities.

If your country already possesses statistics for the consumption of traditional biomass fuels, you need only complete Worksheet 1-3.

Optional Worksheet 1-2 Traditional Biomass Burned for Energy (Fuelwood Consumption Accounting)

This Worksheet estimates wood fuel consumption if the data are not directly available for your country or if they are incomplete.

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary.

STEP 1 ESTIMATING TOTAL ANNUAL WOOD CONSUMPTION

1 Enter the Population (in thousands) as total or in whatever categories can be supported by existing consumption survey data (e.g. rural, urban) in column A.

2 Enter Per Capita Annual Fuelwood Consumption (by population category where appropriate) in kilotonnes of **dry matter** (dm) per 1000 persons, in column B.

No default data are provided. This approach depends upon the user supplying these *per capita* consumption rates. In many developing countries such fuel consumption surveys have been supported by the FAO, the World Bank or other development assistance agencies.

3 Multiply Population (column A) by Per Capita Annual Fuelwood Consumption (column B) to give Total Annual Wood Consumption. Enter the results, in kilotonnes of dry matter, in column C.

STEP 2 ESTIMATING TOTAL ANNUAL CHARCOAL CONSUMPTION

1 Enter Per Capita Annual Charcoal Consumption, in kilotonnes dry matter per 1000 persons, in column D.

2 Multiply Population (column A) by Per Capita Annual Charcoal Consumption (column D) to give Total Annual Charcoal Consumption. Enter the results, in kilotonnes of charcoal, in column E.

STEP 3 ESTIMATING WOOD CONSUMPTION FOR CHARCOAL PRODUCTION

1 Enter Wood to Charcoal Conversion Ratio (in kilotonnes of fuel wood per kilotonne of charcoal) in column F. You should use locally available data where possible (see box).

2 Multiply Total Annual Charcoal Consumption (column E) by the Wood to Charcoal Conversion Ratio (column F) to give the Wood Consumption for Charcoal. Enter the results, in kilotonnes of dry matter, in column G.

WOOD TO CHARCOAL CONVERSION RATIOS

Conversion ratios are highly variable depending on the conditions of the conversion process. Ratios from the literature range from 4:1 (i.e. 4 tonnes dm wood input to produce 1 tonne dm of charcoal) to 8:1, or even higher, depending on the efficiency of the charcoal-making process in a country or region. See the *Reference Manual* for references to published studies. National experts are encouraged to carefully consider the typical conversion processes used in their countries, select a ratio from this range, and explain the reasoning for this ratio. In the worksheet, these ratios are expressed as a multiplier. That is, if the ratio used is 6:1, enter the multiplier 6 in the worksheet to convert tonnes of charcoal consumed into the original wood input to the charcoal production.

STEP 4 ESTIMATING TOTAL WOOD CONSUMPTION FOR FUEL

1 Add Total Annual Wood Consumption (column C) to Wood Consumption for Charcoal (column G) to give Total Wood Consumption for Fuel. Enter the results, in kilotonnes of dry matter, in column H.

2 The totals for Total Annual Wood Consumption (column C), Total Annual Charcoal Consumption (column E) and Wood Consumption for Charcoal (column G) will be used in the next Worksheet.

Worksheet 1-3
Traditional Biomass Burned for Energy

If there is a significant consumption of traditional biomass fuels in your country which is not included in commercial energy statistics, you should first complete Worksheet 1-2: *Traditional Biomass Burned for Energy (Fuelwood Consumption Accounting)*, then use Worksheet 1-3 to continue.

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary.

STEP 1 ESTIMATING CARBON CONTENT OF BIOMASS FUELS

1 For each type of biomass fuel, estimate the annual consumption and enter a value in column A in kilotonnes of dry matter.

Consumption of wood for direct fuel use and of wood for charcoal production may come from Optional Worksheet 1-2.

2 For each type of biomass fuel, estimate the carbon fraction (as a fraction of dry matter) and enter the value in column B.

Default data are shown in Table 1-5.

3 Multiply column A by column B to give the carbon content. Enter the result in column C in kilotonnes of dry matter.

MISSING DATA

You should use locally available data if possible. Otherwise use values for the fuels which you judge to be most similar or use the default values given in Tables 1-5 and 1-6.

TABLE 1-5 BIOMASS FUELS DEFAULT DATA			
Fuel Type	Carbon Fraction	Nitrogen-Carbon Ratio	Fraction Oxidised
Fuelwood	0.45-0.5	0.01	0.87
Charcoal Consumption	0.87	?	0.88
Dung	0.36-0.42	?	0.85
Agricultural Residues[1]	0.4-0.48	0.01-0.02	0.88
[1]These are general default values for crop residues. Specific data for residues are provided in the agricultural burning discussion in Module 4. If consumption data on biomass fuels are available by crop type, these may be used.			
See the *Greenhouse Gas Inventory Reference Manual* for sources.			

STEP 2 ESTIMATING THE TOTAL AMOUNT OF CARBON RELEASED

Direct Combustion (Upper Part of Worksheet 1-3)

1 For each biomass fuel type, enter the fraction oxidised in column D.

Default data is shown in Table 1-5.

2 Multiply carbon content (column C) by the fraction oxidised (column D) to give the Carbon Released for each biomass fuel type and enter the result in column E in kilotonnes of carbon.

Charcoal Production (Lower Part of Worksheet 1-3)

Total carbon released from this process is determined on a mass balance basis, as the difference between the carbon contained in wood (and other materials) used as input to the charcoal production process and the carbon contained in charcoal produced. Use the bottom part of Worksheet 1-3 for this part of the calculation.

1 Enter the annual input of wood and other products to charcoal production, in kilotonnes of dry matter, in the rows "Input (wood)" and "Input (other)" in column A. The "Input (wood)" may be taken from column G of Optional Worksheet 1-2, if used. To the extent possible an estimate of "Other" materials used for charcoal production should be constructed along the lines of Worksheet 1-2.

2 Enter the total annual charcoal production, in kilotonnes of dry matter, in "Output (charcoal)" in column A. This may be taken from column E of Optional Worksheet 1-2, if used.

3 Enter the Carbon Fractions in column B. Default data are shown in Table 1-5. If the default data are used enter the Carbon Fraction shown for Charcoal consumption in the row "Output (charcoal)", column B. No default value is available for "Other" materials used for charcoal manufacture.

4 Multiply the input and output biomass quantities (column A) by the Carbon Fraction (column B) to obtain the carbon content of the

inputs and output, in tonnes of carbon, and enter these values in columns C and E.

5 Determine the carbon released by the charcoal production process, by subtracting the carbon output (row "output (charcoal)", column E) from the carbon input (rows "input (wood)" plus "input (other)", column E). Enter the difference in row "carbon released", column E. Copy this value to row "charcoal production", column E.

STEP 3 ESTIMATING EMISSIONS OF METHANE

1 For each fuel type, enter the C-CH_4 Ratios in column F.

Use Table 1.6 if you require default values.

TABLE 1-6
NON-CO_2 TRACE GAS EMISSIONS RATIOS

Fuel type	C-CH_4/C	C-CO/C	N-N_2O/N	N-NO_X/N
General Biomass	0.010 (0.007-0.013)	0.060 (0.04-0.08)	0.007 (0.005-0.009)	0.121 (0.094-0.148)
Fuelwood	0.012 (0.009-0.015)	NA	NA	NA
Agricultural Residues	0.005 (0.003-0.007)	NA	NA	NA
Dung	0.017	NA	NA	NA
Charcoal Combustion	0.0014	NA	NA	NA
Charcoal Production	0.063 (0.04-0.09)	NA	NA	NA

See the *Greenhouse Gas Inventory Reference Manual* for sources

Note: Ratios for carbon compounds are mass of carbon released as CH_4 or CO (in units of C) relative to mass of total carbon released from burning (in units of C). Those for nitrogen compounds are expressed as the ratios of nitrogen released as N_2O and NO_X relative to the nitrogen content of the fuel (in units of N).

NA = No data available at present - use general biomass values.

2 For each fuel type, multiply the Total Carbon Released by Biomass Fuels (column E) by the Methane-Carbon Ratio (column F) to give the Carbon Emitted as CH_4 from Biomass Burned for Energy. Enter the results in column G in kilotonnes of carbon.

3 Multiply the results in column G by 16/12 to give C emitted as CH_4. Enter the results in gigagrams CH_4 in column H.

STEP 4 ESTIMATING EMISSIONS OF CARBON MONOXIDE

1 Enter the CO-C Trace Gas Emissions Ratios in column I.

Default ratios are given in Table 1-6.

2 Multiply Total Carbon Released (column E) by the Trace Gas Emissions Ratio for CO (column I) to give the amount of Carbon Emitted as CO. Enter the results in column J in kilotonnes of carbon.

3 Multiply Carbon Emitted as CO (column J) by 28/12 to give CO Emitted. Enter the results in gigagrams CO in column K.

STEP 5 ESTIMATING EMISSIONS OF NITROGEN AS NITROUS OXIDE

1 Enter Nitrogen-Carbon Fuel Ratios in column L.

See Table 1-5 for default values.

2 Multiply Carbon Released (column E) by the Nitrogen-Carbon Fuel Ratios (column L) to give Total Nitrogen Released. Enter the result in kilotonnes of nitrogen in column M.

3 Enter the N-N_2O Trace Gas Emission Ratios in column N.

Default ratios are given in Table 1-6.

4 Multiply Total Nitrogen Released (column M) by the N_2O-N Trace Gas Emission Ratio (column N) to give the amount of Nitrogen Emitted as N_2O. Enter the result in kilotonnes of nitrogen in column O.

5 Multiply Nitrogen Released as N_2O (column O) by 44/28[1] to give the amount of N_2O released. Enter the result in gigagrams N_2O in column P.

STEP 6 ESTIMATING EMISSIONS OF NITROGEN AS NITROGEN OXIDES

1 Enter N-NO_X Trace Gas Emission Ratios in column Q.

Default ratios are given in Table 1-6.

2 Multiply Total Nitrogen Released (column M) by the N-NO_X Trace Gas Emission Ratios (column Q) to give Nitrogen Emitted as NO_X. Enter the result in kilotonnes of nitrogen in column R.

3 Multiply Nitrogen Emitted as NO_X (column R) by 46/14 to give the amount of NO_X emitted.

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[1] 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 NO_X it is 46/14. NO_2 has been used as the reference molecule for NO_X.

FUGITIVE SOURCES

1.4 Methane Emissions from Coal Mining and Handling Activities

Introduction

The process of coal formation, commonly called coalification, inherently generates methane and other by-products. The degree of coalification (defined by the rank of the coal) determines the quantity of methane generated and, once generated, the amount of methane stored in coal is controlled by the pressure and temperature of the coal seam and by other, less well-defined characteristics of the coal. The methane will remain stored in the coal until the pressure on the coal is reduced, which can occur through the erosion of overlying strata or the process of coal mining. Once the methane has been released, it flows through the coal toward a region of lower pressure (such as a coal mine) and into the atmosphere.

The amount of CH_4 generated during coal mining is primarily a function of coal rank and depth, as well as other factors such as moisture. If two coal seams have the same rank, the deeper seam will hold larger amounts of CH_4 because the pressure is greater at lower depths, all other things being equal. As a result, most methane released to the atmosphere from coal mining is assumed to come from underground rather than surface mining. As a result, the methane emission factors for surface-mined coal are assumed to be lower than for underground mining.

Methane is also emitted from post-mining activities such as coal processing, transportation, and utilisation. Methane is released mainly because the increased surface area allows more CH_4 to desorb from the coal. Transportation of the coal contributes to CH_4 emissions, because CH_4 desorbs directly from the coal to the atmosphere while in transit (e.g., in railroad cars). Coal may also release methane during its preparation for final use. For instance, in steel production coal is crushed to a particle size of less than 5 mm, vastly increasing the surface area of the coal and allowing more CH_4 to desorb.

Data Sources

The basic data necessary to perform these calculations are, at a minimum, quantity of coal mined by type of mine (underground or surface). Use locally available data where these are reliable.

Country statistics on underground and surface coal production are available from the OECD/IEA (for certain OECD Member countries). Data on coal production by type (hard coal and lignite) are also available for most countries in the world.

ALTERNATIVE LEVELS OF DETAIL - TIERS

The information provided in this *Workbook*, including global default emission factors, allows for calculation at the *Tier 1* level. *Tier 2* calculations follow the same structure, but would use country or basin-specific emission factors if available locally. If a country is capable of *Tier 3* estimates this would indicate that the emissions estimates are already available (having been directly measured) and the *Workbook* methodology for calculating emissions is not needed. Countries with *Tier 3* estimates can move directly to the *Reporting Instructions* volume of these *Guidelines* for guidance on reporting and documenting emissions estimates.

The highest tier of estimation methodology possible should be used for each component of mining activity. It is acceptable to provide estimates using different tiers for various components, provided that the level of calculation is clearly identified in each component. For example, even if *Tier 3* is used to estimate underground emissions, *Tier 1* or 2 can be used to estimate emissions from other components of mining activity.

Methodology

On the advice of an expert group (see the *Greenhouse Gas Inventory Reference Manual*), calculations have been organised around a single formula which relates tonnes of coal production to total CH_4 emissions from *mining* and *post-mining* activities.

The *Workbook* enables the user to operate at several different levels of detail or "tiers" (discussed in more detail in the *Reference Manual*).

Tier 1 is the least accurate and is based upon global average emission factors.

Tier 2 is possible when a country has enough information to develop average emission factors of its own. More detailed calculations can be accommodated by making extra copies of the worksheet and breaking the calculations into sub-national components for which more specific emissions factors may be available.

Tier 3 is based on mine-specific measurement of emissions from mine ventilation and degasification. This method is recommended if data are available as it should provide much more accurate country-based estimates.

The equation for calculating CH_4 emissions from mining activities is:

CH_4 Emissions	=	Coal Production	x	Emission Factor	x	Conversion Factor
(Gg)		(10^6 t)		(m^3 CH_4 / tonne coal)		(Gg CH_4 / 10^6 m^3 CH_4)

Completing the Worksheet

Use WORKSHEET 1-4 METHANE EMISSIONS FROM COAL MINING AND HANDLING to enter your data for this submodule.

STEP 1 ESTIMATING METHANE EMISSIONS FROM COAL MINING AND HANDLING

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary

1 Enter the amount of coal produced by each type of mining activity, in millions of tonnes, in column A.

The total amount of coal should be consistent with that used in the CO_2 from Energy submodule (Worksheet 1-1, sheet 1, column A).

2 Select an Emission Factor using Table 1-7 below. Do this for each type of mining activity involved in your inventory. Select a point within the possible range of values which is appropriate to your country. If you do not have the information to select a point, use an average value. Enter the value in column B.

TABLE 1-7
HIGH AND LOW EMISSION FACTORS FOR MINING ACTIVITIES (M^3/TONNE)

	Type of Mine/Activity	
Emission Factor	*Underground*	*Surface*
Mining	10 - 25	0.3 - 2.0
Post-mining	0.9 - 4.0	0 - 0.2

Source: Compiled from various country studies as summarised in Reference Manual

3 Multiply the Amount of Coal Produced (column A) by the Emission Factor (column B) to give Methane Emissions (in millions of cubic metres) for each type of mining activity. Enter the result in column C.

STEP 2 CONVERTING METHANE EMISSIONS IN M^3 TO METHANE EMISSIONS IN GIGAGRAMS

1 Enter a Conversion Factor in column D.

The conversion factor converts volume of CH_4 to a weight measure (gigagrams) using the density of methane at 20°C and at a pressure of 1 atmosphere. This conversion factor, expressed in a form suitable for this *Workbook*, is 0.67 $Gg/10^6 m^3$.

2 Multiply the Methane Emissions in millions of m^3 by the Conversion Factor to give the Methane Emissions in gigagrams. Enter the result in column E. Add the figures and enter the total in the Total box at the bottom of the column.

1.5 Fugitive Methane Emissions from Oil and Natural Gas Activities

Introduction

Fugitive emissions of methane from oil and gas activities probably account for about 30 to 70 teragrams per year of global methane emissions. The category includes all emissions from the production, processing, transport and use of oil and natural gas, and from non-productive combustion. It excludes use of oil and gas or derived fuel products to provide energy for internal use, in energy production processing and transport. The latter are considered fuel combustion and treated in an earlier section of this chapter. Fugitive emissions do include, however, emissions which result from the combustion of natural gas during flaring operations. Sources of emissions within oil and gas systems include:

- emissions during normal operation, such as emissions associated with venting and flaring during oil and gas production, chronic leaks or discharges from process vents;
- emissions during repair and maintenance, ; and
- emissions during system upsets and accidents.

To calculate methane emissions from oil and gas activities in your country, you require the following energy data:

Oil	**Gas**
Number of wells drilled	Quantity of gas produced
Quantity of oil produced	Quantity of gas consumed
Quantity of oil refined	

In addition, emission factors will be required as discussed below.

Data sources

Locally available data should be used wherever possible. Energy data for a large number of countries are also published by the International Energy Agency and the United Nations Statistical Division. See *Reference Manual* Chapter 1, Section 1.9.2 and 1.9.3.

In addition to energy data, default emissions factors, and other input assumptions, are provided in the *Workbook* methodology where available. In calculating national emissions, users of this method are free to override any of these assumptions or recommendations if other information is preferred. Wherever information is used other than the values recommended in the *Workbook*, this should be noted and documentation should be provided on the sources of the information.

Users should ensure that data used in this section are consistent with those entered in the *CO_2 from Energy* calculations. Countries which have significant emissions from oil and natural gas should consult the discussion in the *Reference*

Manual and look for locally available data which will allow the development of more country-specific factors.

Methodology

Three different *tiers* or levels of detail for calculating these emissions are presented in the *Reference Manual.*

- Tier 1 Production-Based Average Emission Factors Approach
- Tier 2 Mass Balance Approach
- Tier 3 Rigorous Source-Specific Approach

Only Tier 1 is presented in this *Workbook.*

This requires assembling activity data (production etc.) for the country, selecting emission factors based on information in the tables of typical regional values (or from locally available data), and multiplying through to produce emissions estimates by major subcategory. Explanations of the regions used are provided below.

Regional Definitions

Regions have been defined recognising the limitations in data on emissions factors and activity levels, and key differences in oil and gas activities throughout the world. The following five regions have been chosen:

- **US and Canada**:
- **Former USSR and Eastern Europe**: This region includes the former USSR (which is by far the largest oil and gas producer in the region), Albania, Bulgaria, Czech & Slovak Republics, Hungary, Poland, Romania, and the former Yugoslav republics.
- **Western Europe**: This region includes: Austria, Belgium, Denmark, Faroe Islands, Finland, France, Germany, Gibraltar, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom.
- **Other Oil Exporting Countries**: This region includes the world's other major oil producing countries: the 13 OPEC members (Algeria, Gabon, Libya, Nigeria, Ecuador, Venezuela, Indonesia, Iran, Iraq, Kuwait, Qatar, Saudi Arabia and the United Arab Emirates) and Mexico.
- **Rest of the World**: This region includes the remaining countries of Asia, Africa, Middle East, Oceania and Latin America.

Completing the Worksheet

Use WORKSHEET 1-5 METHANE EMISSIONS FROM OIL AND GAS ACTIVITIES to enter your data for this submodule.

ESTIMATING THE AMOUNT OF METHANE EMITTED BY OIL AND GAS ACTIVITIES

EXPLORATION AND DRILLING

A category of exploration and drilling is included on the Worksheet. However, no sources of activity data or default emissions are provided. If you have locally available data for these values, enter this. If you are working from default sources you should ignore this category which is only expected to be a small component of emissions.

1 Enter data for each type of oil and gas production activity in column A.

Data sources are discussed above. Ensure that the data you use are consistent with the activity data used to calculate CO_2 from Energy Sources in the first submodule of this module.

2 For each type of activity enter an Emission Factor in column B.

Use locally available data or the data in Table 1-8 below. Note that these tables provide a range of values to account for the uncertainty implicit in this method. You should use your judgement to select a single value from this range. You are also encouraged to provide an estimate of uncertainty with the values (see the *Greenhouse Gas Inventory Reporting Instructions*).

3 Multiply the amounts of oil and gas for each Activity (column A) by the Emission Factor (column B) to give the amount of CH_4 emitted in kilograms CH_4. Enter the results in kilograms in column C.

4 Divide the emissions of CH_4 in kilograms (column C) by 10^6 to convert to gigagrams. Enter the results, in gigagrams CH_4, in column D and complete the "total" boxes.

TABLE I-8

REVISED REGIONAL EMISSION FACTORS FOR METHANE FROM OIL AND GAS ACTIVITIES SYSTEMS (kg/PJ)

Source Type	Basis	Western Europe	US & Canada	Former USSR, Central & Eastern Europe	Other Oil Exporting Countries	Rest of the World
OIL & GAS PRODUCTION						
Fugitive and Other Routine Maintenance Emissions from Oil Production	Oil Produced	300 - 5,000	300 - 5,000	300 - 5,000	300 - 5,000	300 - 5,000
Fugitive and Other Routine Maintenance Emissions from Gas Production	Gas Produced	15,000 - 27,000	46,000 - 84,000	140,000 - 314,000	46,000 - 96,000	46,000 - 96,000
Venting & Flaring from Oil and Gas Production	Oil & Gas Produced[1]	-	3,000 - 14,000	-	-	-
	Oil Produced	1,000 - 3,000	-	-	-	-
	Gas Produced	-	-	6,000 - 30,000	758,000 - 1,046,000	175,000 - 209,000
CRUDE OIL TRANSPORTATION, STORAGE AND REFINING						
Transportation	Oil Tankered	745	745	745	745	745
Refining	Oil Refined	90 - 1,400	90 - 1,400	90 - 1,400	90 - 1,400	90 - 1,400
Storage Tanks	Oil Refined	20 - 250	20 - 250	20 - 250	20 - 250	20 - 250
NATURAL GAS PROCESSING, TRANSPORT AND DISTRIBUTION						
Emissions from Processing, Transmission and Distribution	Gas Produced	-	-	288,000 - 628,000	288,000 (high)[2]	288,000 (high)[2]
	Gas Consumed	72,000 - 133,000	57,000 - 118,000	-	118,000 (low)[3]	118,000 (low)[3]
Leakage at industrial plants and power stations	Non-residential Gas Consumed[4]	-	-	175,000 - 384,000	0 - 175,000	0 - 175,000
Leakage in the residential and commercial sectors	Residential Gas Consumed[5]	-	-	87,000 - 192,000	0 - 87,000	0 - 87,000

1. In the US and Canada, the emissions are based on total production of both oil and gas produced.

2. The emission factor of 288,000 kg/PJ of gas produced is used only for the high emissions estimate.

3. The emission factor of 118,000 kg/PJ of gas consumed is used only for the low emissions estimate.

4. Gas consumption by utilities and industries.

5. Gas consumption by the residential and commercial sectors.

Source: Constructed from the literature summarised in the *Reference Manual*

		MODULE	**ENERGY**					
		SUBMODULE	**CO_2 FROM ENERGY SOURCES (REFERENCE APPROACH)**					
		WORKSHEET	**1-1**					
		SHEET	**1 OF 5**					
			STEP 1					
			A Production	B Imports	C Exports	D International Bunkers	E Stock Change	F Apparent Consumption
FUEL TYPES								F=(A+B -C-D-E)
Liquid Fossil	Primary Fuels	Crude Oil						
		Natural Gas Liquids						
	Secondary Fuels	Gasoline						
		Jet Kerosene						
		Other Kerosene						
		Gas / Diesel Oil						
		Residual Fuel Oil						
		LPG						
		Ethane						
		Naphtha						
		Bitumen						
		Lubricants						
		Petroleum Coke						
		Refinery Feedstocks						
		Other Oil						
Liquid Fossil Totals								
Solid Fossil	Primary Fuels	Anthracite[1]						
		Coking Coal						
		Other Bit. Coal						
		Sub-bit. Coal						
		Lignite						
		Peat						
	Secondary Fuels	BKB & Patent Fuel						
		Coke						
Solid Fossil Totals								
Gaseous Fossil		Natural Gas (Dry)						
Total								
Biomass Total								
		Solid biomass						
		Liquid biomass						
		Gas biomass						

[1] If anthracite is not separately available, include with Other Bituminous Coal.

		MODULE	**ENERGY**				
		SUBMODULE	**CO_2 FROM ENERGY SOURCES (REFERENCE APPROACH)**				
		WORKSHEET	**1-1**				
		SHEET	**2 OF 5**				
			STEP 2		**STEP 3**		
			G[1] Conversion Factor (TJ/Unit)	H Apparent Consumption (TJ)	I Carbon Emission Factor (t C/TJ)	J Carbon Content (t C)	K Carbon Content (Gg C)
FUEL TYPES				H=(FxG)		J=(HxI)	$K=(J\times10^{-3})$
Liquid Fossil	Primary Fuels	Crude Oil					
		Natural Gas Liquids					
	Secondary Fuels	Gasoline					
		Jet Kerosene					
		Other Kerosene					
		Gas / Diesel Oil					
		Residual Fuel Oil					
		LPG					
		Ethane					
		Naphtha					
		Bitumen					
		Lubricants					
		Petroleum Coke					
		Refinery Feedstocks					
		Other Oil					
Liquid Fossil Totals							
Solid Fossil	Primary Fuels	Anthracite					
		Coking Coal					
		Other Bit. Coal[2]					
		Sub-bit. Coal					
		Lignite					
		Peat					
	Secondary Fuels	BKB & Patent Fuel					
		Coke					
Solid Fossil Totals							
Gaseous Fossil		Natural Gas (Dry)					
Total							
Biomass Total							
		Solid biomass					
		Liquid biomass					
		Gas biomass					

[1] Please specify units

[2] If anthracite is not separately available, include with Other Bituminous Coal

		MODULE	**ENERGY**				
		SUBMODULE	**CO_2 FROM ENERGY SOURCES (REFERENCE APPROACH)**				
		WORKSHEET	**1-1**				
		SHEET	**3 OF 5**				
			STEP 4		**STEP 5**		**STEP 6**
			L	M	N	O	P
			Carbon Stored (Gg C)	Net Carbon Emissions (Gg C)	Fraction of Carbon Oxidised	Actual Carbon Emissions (Gg C)	Actual CO_2 Emissions (Gg CO_2)
FUEL TYPES				M=(K-L)		O=(MxN)	P=(Ox[44/12])
Liquid Fossil	Primary Fuels	Crude Oil					
		Natural Gas Liquids					
	Secondary Fuels	Gasoline					
		Jet Kerosene					
		Other Kerosene					
		Gas / Diesel Oil					
		Residual Fuel Oil					
		LPG					
		Ethane					
		Naphtha					
		Bitumen					
		Lubricants					
		Petroleum Coke					
		Refinery Feedstocks					
		Other Oil					
Liquid Fossil Totals							
Solid Fossil	Primary Fuels	Anthracite					
		Coking Coal					
		Other Bit. Coal[1]					
		Sub-bit. Coal					
		Lignite					
		Peat					
	Secondary Fuels	BKB & Patent Fuel					
		Coke					
Solid Fossil Totals							
Gaseous Fossil		Natural Gas (Dry)					
Total							
Biomass Total							
		Solid biomass					
		Liquid biomass					
		Gas biomass					

[1] If anthracite is not separately available, include with Other Bituminous Coal

MODULE		**ENERGY**					
SUBMODULE		**CO_2 FROM ENERGY SOURCES (REFERENCE APPROACH)**					
WORKSHEET		**1-1**					
SHEET		**4 OF 5 EMISSIONS FROM INTERNATIONAL BUNKERS (INTERNATIONAL MARINE AND AIR TRANSPORT)**					
		STEP 1	**STEP 2**		**STEP 3**		
		A Quantities Delivered[1]	B Conversion Factor (TJ/unit)	C Quantities Delivered (TJ)	D Carbon Emission Factor (t C/TJ)	E Carbon Content (t C)	F Carbon Content (Gg C)
FUEL TYPES				C=(AxB)		E=(CxD)	F=(E x 10^{-3})
Solid Fossil	Other Bituminous Coal						
	Sub-Bituminous Coal						
Liquid Fossil	Gasoline						
	Jet Kerosene						
	Gas/Diesel Oil						
	Residual Fuel Oil						
	Lubricants						
			Total				

[1] Enter the quantities from Table 1-1, Sheet 1, column D: "International Bunkers"

	MODULE	**ENERGY**					
	SUBMODULE	**CO_2 FROM ENERGY SOURCES (REFERENCE APPROACH)**					
	WORKSHEET	**1-1**					
	SHEET	**5 OF 5 EMISSIONS FROM INTERNATIONAL BUNKERS (INTERNATIONAL MARINE AND AIR TRANSPORT)**					
		STEP 4			**STEP 5**		**STEP 6**
		G Fraction of Carbon Stored	H Carbon Stored (Gg C)	I Net Carbon Emissions (Gg C)	J Fraction of Carbon Oxidised	K Actual Carbon Emissions (Gg C)	L Actual CO_2 Emissions (Gg CO_2)
FUEL TYPES			H=(FxG)	I=(F-H)		K=(IxJ)	L=(Kx44/12)
Solid Fossil	Other Bituminous Coal	0	0				
	Sub-Bituminous Coal	0	0				
Liquid Fossil	Gasoline	0	0				
	Jet Kerosene	0	0				
	Gas/Diesel Oil	0	0				
	Residual Fuel Oil	0	0				
	Lubricants	0.5					
						Total[1]	

[1] The bunker emissions are not to be added to national totals.

MODULE	**ENERGY**
SUBMODULE	**CO_2 FROM ENERGY**
WORKSHEET	**AUXILIARY WORKSHEET 1-1 - ESTIMATING CARBON STORED IN PRODUCTS**
SHEET	**1 OF 1**

	A Estimated Fuel Quantities	B Conversion Factor (TJ/Units)	C Estimated Fuel Quantities (TJ)	D Carbon Emission Factor (t C/TJ)	E Carbon Content (t C)	F Carbon Content (Gg C)	G Fraction of Carbon Stored	H Carbon Stored (Gg C)
FUEL TYPES			C=(AxB)		E=(CxD)	F=(Ex10^{-3})		H=(FxG)
Naphtha[1]							0.80	
Lubricants							0.50	
Bitumen							1.0	
Coal Oils and Tars (from Coking Coal)							0.75	
Natural Gas[1]							0.33	
Gas/Diesel Oil[1]							0.50	
LPG[1]							0.80	
Other fuels[2]								

1 Enter these fuels when they are used as feedstocks.

2 Use the Other fuels rows to enter any other products in which carbon may be stored

	MODULE	ENERGY						
	SUBMODULE	TRADITIONAL BIOMASS BURNED FOR ENERGY						
	WORKSHEET	1-2 OPTIONAL FUELWOOD CONSUMPTION ACCOUNTING						
	SHEET	1 OF 1						
	STEP 1			STEP 2		STEP 3		STEP 4
Population Category (e.g. rural, urban, etc.) (specify)	A Population (by category) (1000 persons)	B Per Capita Annual Fuelwood Consumption (kt dm/1000 persons)	C Total Annual Wood Consumption (kt dm)	D Per Capita Annual Charcoal Consumption (kt dm/1000 persons)	E Total Annual Charcoal Consumption (kt charcoal)	F Wood to Charcoal Conversion Ratio (kt fuelwood / kt charcoal)	G Wood Consumption for Charcoal (kt dm)	H Total Wood Consumption for Fuel (kt dm)
			C=(AxB)		E=(AxD)		G=(ExF)	H=(C+G)
		Totals						

MODULE	**ENERGY**
SUBMODULE	**TRADITIONAL BIOMASS BURNED FOR ENERGY**
WORKSHEET	**1-3**
SHEET	**1 OF 3**

	STEP 1			STEP 2			STEP 3	
	A Biomass Consumed (kt dm)	B Carbon Fraction of Biomass	C Carbon Content (kt dm)	D Fraction Oxidised	E Total Carbon Released by Biomass Fuels (kt C)	F C-CH_4 Ratio	G Carbon Emitted as CH_4 (kt C)	H CH_4 Emissions from Biomass Burned (Gg CH_4)
			C=(AxB)		E=(CxD)		G=(ExF)	H=(G[16/12])
Wood (for direct use)	(a)							
Agricultural Wastes								
Dung								
Charcoal Consumption	(b)							
Charcoal Production					(c)			
Others (Specify)								
				Total				
Charcoal Production								
Input (Wood)	(d)							
Input (Other)[e]								
Output (Charcoal)								
Carbon Released					(c)			

a Total wood consumption from column C of Worksheet 1-2 if used.

b Charcoal consumption for energy use. This will be the quantity shown in column A, output (charcoal) adjusted for any charcoal used for non-energy purposes. It will also equal column E, total, of Worksheet 1-2 if used.

c Carbon released from charcoal production equals carbon input (wood and other) minus carbon output (charcoal).

d Total wood consumption from column G of Worksheet 1-2 if used.

e E.g. coconut shells. Please specify.

MODULE	ENERGY							
SUBMODULE	TRADITIONAL BIOMASS FUEL BURNED FOR ENERGY							
WORKSHEET	1-3							
SHEET	2 OF 3							
	STEP 4			STEP 5				
	I C-CO Trace Gas Emission Ratio	J C Emitted as CO (kt C)	K CO Emitted (Gg CO)	L Nitrogen-Carbon Fuel Ratio	M Total Nitrogen Released (kt N)	N N-N_2O Trace Gas Emissions Ratio	O Nitrogen Emitted as N_2O (kt N)	P N_2O Emitted (Gg N_2O)
		J=(ExI)	K=(Jx28/12)		M=(ExL)		O=(MxN)	P=(Ox44/28)
Wood								
Agricultural Wastes								
Dung								
Charcoal Consumption								
Charcoal Production								
Others (Specify)								
		Total					Total	

MODULE	ENERGY		
SUBMODULE	TRADITIONAL BIOMASS FUEL BURNED FOR ENERGY		
WORKSHEET	1-3		
SHEET	3 OF 3		
	STEP 6		
	Q $N\text{-}NO_x$ Trace Gas Emissions Ratio	R Nitrogen Emitted as NO_x (kt N)	S NO_x Emitted (Gg of NO_x)
		R=(MxQ)	S=(Rx46/14)
Wood			
Agricultural Wastes			
Dung			
Charcoal Consumption			
Charcoal Production			
Others (Specify)			
		Total	

	MODULE	**ENERGY**				
	SUBMODULE	**METHANE EMISSIONS FROM COAL MINING AND HANDLING**				
	WORKSHEET	**1-4**				
	SHEET	**1 OF 1**				
		STEP 1			**STEP 2**	
		A Amount of Coal Produced (million t)	B Emission Factor (m^3 CH_4/t)	C Methane Emissions (million m^3)	D Conversion Factors (0.67 Gg $CH_4/10^6$ m^3)	E Methane Emissions (Gg CH_4)
				C=(AxB)		E=(CxD)
Underground Mines	Mining				0.67	
	Post-Mining				0.67	
Surface Mines	Mining				0.67	
	Post-Mining				0.67	
					Total	

MODULE	ENERGY
SUBMODULE	METHANE EMISSIONS FROM OIL AND GAS ACTIVITIES (TIER 1 APPROACH)
WORKSHEET	1-5
SHEET	1 OF 1

Category	A Activity	B Emission Factor	C CH_4 Emissions (kg CH_4)	D Emissions CH_4 (Gg CH_4)
OIL			C=(AxB)	D=(C/10^6)
Exploration *(Optional if data is locally available)* [1]	*number of wells drilled*	*kg CH_4/well drilled*		
Production[2]	*PJ oil produced*	*kg CH_4/PJ*		
Transport	*PJ oil loaded in tankers*	*kg CH_4/PJ*		
Refining	*PJ oil refined*	*kg CH_4/PJ refined*		
Storage	*PJ oil refined*	*kg CH_4/PJ refined*		
			TOTAL CH_4 FROM OIL	
GAS				
Production[2]/ Processing	*PJ gas produced*	*kg CH_4/PJ*		
Transmission and Distribution	*PJ gas consumed*	*kg CH_4/PJ*		
Other Leakage	*PJ gas consumed* *- non-residential gas consumed (PJ)* *- Residential gas consumed*			
			TOTAL CH_4 FROM GAS	
VENTING AND FLARING FROM OIL/GAS PRODUCTION[3]	*PJ oil and gas produced* *- Oil* *- Gas* *- Combined*	*kg CH_4/PJ*		
			TOTAL CH_4 EMISSIONS FROM OIL AND GAS	

1 Emission Factors are not provided.

2 If using default emission factors these categories will include emissions from production other than venting and flaring.

3 If using default emission factors, emissions from venting and flaring from all oil and production should be accounted for here.

MODULE 2
INDUSTRIAL PROCESSES

2 INDUSTRIAL PROCESSES

2.1 Introduction

This module gives instructions for calculating greenhouse gas emissions from cement production. This is the most important industrial source of CO_2.

Other industrial sources of CO_2 and other greenhouse gases are discussed in the *Greenhouse Gas Inventory Reference Manual.*

No other default methods for industrial processes are provided in this version of the *Workbook*, although some additional sources are listed in the following section.

CO_2 from other Industrial processes

A variety of non-energy industrial processes produce CO_2 emissions. These are production processes in which materials are transformed from one state into another and in which CO_2 is emitted as a by-product of chemical reactions. Most of these processes also include fuel combustion which produces CO_2 emissions, but the IPCC methodology used in this *Workbook* treats combustion and non-combustion components separately. Cement production is believed to be the most important process source of CO_2 and is the only category for which an explicit method is included in the *Workbook*. However, many other processes may be significant for some other countries. In the national inventories collected by the IPCC/OECD programme CO_2 emissions from the following processes have been reported:

Production	coke, iron, steel, aluminium, ferro-alloys, fertilisers, limestone, lime, dolomite, bricks, glass, paper, pulp and print, soda ash and CO_2 manufacture.
Consumption	limestone and soda ash.

In general we expect that most categories will follow the simple method recommended for cement production:

Physical units of production (e.g. tonnes of product)	x	**Emission Factor (tonnes CO_2/tonne product)**	=	**Emissions (tonnes CO_2)**

As more national data is collected and evaluated in this area, we expect to be able to develop and provide formulae and default emissions factors for additional categories.

2.2 CO_2 from Cement Production

Introduction

Carbon dioxide emitted during the cement production process represents the largest non-energy source of industrial carbon dioxide emissions. Cement production accounts for about 2.4 percent of total global industrial and energy CO_2 emissions (Marland et al., 1989). Carbon dioxide is produced during the production of clinker, an intermediate product from which cement is made. High temperatures in cement kilns chemically change raw materials into cement clinker. In a process called *calcination* or *calcining*, calcium carbonate is heated, forming lime and carbon dioxide. This lime then undergoes additional processes to form clinker, and finally cement.

It should be noted that when poured concrete is curing, some CO_2 is reabsorbed by the concrete from the atmosphere. This CO_2 reabsorption is, however, believed to be only a small fraction of the CO_2 emission resulting from cement production and is therefore usually ignored in emission calculations.

Most of the structural cement currently produced in the world is of the "Portland" cement type, which contains 60 to 67 percent lime by weight. Other speciality cements are lower in lime, but are typically used in small quantities. Carbon dioxide emissions from cement production are essentially directly proportional to lime content, so production of cements lower in lime yield less CO_2. The methodology presented in the *Workbook* is for the Portland type cement.

Data sources

International cement production data are available from the United Nations (1988) and from the US Bureau of Mines (1988). In some countries, national data may be available from appropriate government ministries. There is substantial overlap between US Bureau of Mines and the UN data sets, but the former is more complete. A trade association, European Cement Associations (CEMBUREAU) also publishes information (see CEMBUREAU, 1990, *World Cement Market in Figures* and *World Statistical Review*).

Methodology

Because carbon dioxide is emitted specifically during clinker production, rather than during cement production itself, emission estimates should be based on the lime content and production of clinker. This recognises the consideration that some domestic cement may be made from imported clinker, and that some finished cement may use additional lime that is not accounted for in the clinker calculations. Clinker statistics, however, may not be readily available in some countries. If this is the case, cement production statistics can be used. The differences between the lime content and production of clinker and cement, *in most countries*, are not significant enough to affect the emission estimates.

Estimation of CO_2 emissions from cement production is accomplished by applying an emission factor, in tonnes of CO_2 released per tonne of clinker produced, to the annual clinker output. The recommended emission factor for clinker is 0.5071 tonnes of CO_2 per tonne of clinker produced.

If information on clinker production is not readily available, an emissions factor in tonnes of CO_2 released per tonne of cement produced can be applied to annual cement production instead. The recommended emission factor for cement production is 0.4985 tonnes of CO_2 per tonne of cement produced.

This is based on the assumption that the average CaO content of the cement by weight is 63.5 per cent. If the fraction (f) of lime in the cement is known to be different from 0.635 then the following conversion should be made:

Emission factor (t CO_2/t cement) = 0.4985 x (f) / 0.635

In most countries the difference in results between the two methods is likely to be small. Any error in the lime content assumption is likely to be smaller than the uncertainty in the cement production figures.

Completing the Worksheet

Use WORKSHEET 2-1 CO2 EMISSIONS FROM CEMENT PRODUCTION to enter data for this submodule.

USING THE WORKSHEET

- Photocopy the Production processes Worksheet at the end of this section to complete the inventory.
- Keep the original clean so that you can make further copies if necessary.

STEP 1 ESTIMATING CO_2 EMITTED

1 Estimate clinker production, or if data on clinker production is not available, estimate cement production, and enter this value in column A in tonnes.

2 Enter the corresponding emissions factor in column B in tonnes CO_2 per tonne of clinker or cement produced.

3 Multiply column A by column B to get CO_2 emitted in tonnes of CO_2, and enter this value in column C.

STEP 2 CONVERT TO Gg

4 Divide column C by 1000 to convert to units of gigagrams CO_2, and enter this value in column D.

MODULE	INDUSTRIAL PROCESSES		
SUB MODULE	CO_2 FROM CEMENT PRODUCTION		
WORKSHEET	2-1		
SHEET	1 OF 1		
STEP 1			STEP 2
A Amount of Clinker or Cement Produced: (t)	B Emissions Factor (t CO_2/t Clinker or Cement Produced)	C CO_2 emitted: (t)	D CO_2 emitted: (Gg)
		C=(AxB)	D=C/1000

MODULE 3

SOLVENT AND OTHER PRODUCT USE

3 SOLVENT AND OTHER PRODUCT USE

No methods for the calculation of greenhouse gases (primarily Non-Methane Volatile Organic Compounds) from solvent and other product use are included in the phase I version of the workbook. This placeholder is provided to preserve numbering consistency with the *Greenhouse Gas Inventory Reference Manual*, (*Guidelines* Volume 3) and the *Greenhouse Gas Inventory Reporting Instructions*, (*Guidelines* Volume 1).

MODULE 4
AGRICULTURE

4 AGRICULTURE

4.1 Introduction

The Agriculture module looks at greenhouse gas emissions from four sources:

- Domestic Livestock: Enteric Fermentation and Manure Management
- Rice Cultivation: Flooded Rice Fields
- Prescribed Burning of Savannas
- Field Burning of Agricultural Residues

The primary focus is on methane emissions in this Phase I edition of the *Workbook*. Other subcategories such as nitrous oxide from agricultural soils will be added in future editions.

4.2 Domestic Livestock

Introduction

This submodule deals with methane emissions from two sources:

- enteric fermentation
- *manure management*

Methane from enteric fermentation is produced in herbivores as a by-product of the digestive process by which carbohydrates are broken down by micro-organisms into simple molecules for absorption into the blood-stream. Both ruminant animals (e.g. cattle, sheep) and some non-ruminant animals (e.g. pigs, horses) produce methane, although ruminants are the largest source. The amount of CH_4 that is released depends upon the type, age and weight of the animal and the quantity and quality of the feed consumed.

Methane from the management of animal manure occurs as the result of its decomposition under anaerobic conditions. These conditions often occur when a large number of animals are managed in a confined area (e.g. dairy farms, beef feedlots, and swine and poultry farms).

Emissions of methane from wild animals and termites are not included in this submodule. The focus in the IPCC *Guidelines* is on anthropogenic emissions. While there are human interactions with natural sources such as wild animals and termites, they are complex and highly uncertain.

Data sources

There are no individual sources that will provide all the data needed to estimate methane emissions from domestic livestock. The Food and Agriculture Organisation (FAO) of the United Nations publishes a series entitled *The FAO Production Yearbook* (e.g., FAO, 1991). This series has information about livestock populations and the production and consumption of livestock products. The FAO data should be supplemented with studies conducted for individual countries. Many countries publish results of their agricultural census that includes data on production levels in addition to livestock populations. Table 4-1 summarises the data needed.

TABLE 4-1
LIVESTOCK POPULATION DATA COLLECTED IN TIER 1 STEP 1

Livestock	Data Collected				
	Population (# head)	Milk Production (kg/head/yr)	Population By Climate (%)		
			Cool	Temperate	Warm
Dairy Cattle	Average Annual Population	Milk Production per Head	% Cool	% Temp.	% Warm
Non-Dairy Cattle	Average Annual Population	Not Applicable (NA)	% Cool	% Temp.	% Warm
Buffalo	Average Annual Population	(NA)	% Cool	% Temp.	% Warm
Sheep	Average Annual Population	(NA)	% Cool	% Temp.	% Warm
Goats	Average Annual Population	(NA)	% Cool	% Temp.	% Warm
Camels	Average Annual Population	(NA)	% Cool	% Temp.	% Warm
Horses	Average Annual Population	(NA)	% Cool	% Temp.	% Warm
Mules and Asses	Average Annual Population	(NA)	% Cool	% Temp.	% Warm
Swine	Average Annual Population	(NA)	% Cool	% Temp.	% Warm
Poultry	Average Annual Population	(NA)	% Cool	% Temp.	% Warm

Climate regions are defined in terms of annual average temperature as follows: Cool = less than 15°C; temperate = 15°C to 25°C inclusive; and warm = greater than 25°C.

Methodology

Although the methodological issues are very complex, a simplified methodology is used for the purposes of this *Workbook*.

For a detailed discussion of the methodology, see the *Greenhouse Gas Inventory Reference Manual*. Broadly, emissions are calculated by applying an emission factor to the number of animals of each livestock type in the country to produce a total for enteric fermentation. Default emission factors are provided for developed and developing countries with more regional detail for cattle, the most important source from this activity.

The same basic methodology is used to estimate emissions from manure management. In this area default emission factors are provided by region and for three different climate regimes. Simple multiplication of populations by emission factors produces emissions estimates.

Completing the Worksheet

Use WORKSHEET 4-1 METHANE EMISSIONS FROM DOMESTIC LIVESTOCK ENTERIC FERMENTATION AND MANURE MANAGEMENT at the end of this section to record the data.

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary.

STEP 1 ESTIMATING EMISSIONS FROM ENTERIC FERMENTATION

1 For each type of livestock in the Worksheet, enter the number in thousands in column A.

Refer to FAO Production Yearbooks (e.g. FAO 1991) if there are no locally available data. It is recommended that national experts use three-year averages for activity data if available so that the data not be skewed in the event that the base year of the inventory was an exceptional year not representative of the country's normal activity level.

2 For each type of livestock, enter an average Emission Factor in column B in kilograms per head per year (this is the same as tonnes per thousand head per year). Use a figure from the tables below or more precise locally available data. Because cattle are the most important source and because the emission factors for cattle vary significantly among regions, region-specific default factors are provided. Choose emission factors for cattle that are most appropriate for your national situation.

TABLE 4-2
ENTERIC FERMENTATION METHANE EMISSIONS FACTORS
(kg CH_4 per head per year *or* t CH_4 per 1000 head per year)

Livestock	Developed Countries	Developing Countries
Buffalo	55	55
Sheep	8	5
Goats	5	5
Camels	46	46
Horses	18	18
Mules and Asses	10	10
Swine	1.5	1.0
Poultry	Not estimated	Not estimated

All Estimates are + or - 20%.

See the *Greenhouse Gas Inventory Reference Manual* for sources.

3 Multiply the number of cattle by the Average Emissions Factors to give Emissions from Enteric Fermentation in tonnes per year. Enter the result in column C.

TABLE 4-3 (A)
ENTERIC FERMENTATION METHANE EMISSION FACTORS FOR CATTLE

Regional Characteristics	Cattle Type	Emissions Factor (kg CH_4/head /yr)	Comments
***North America*:** Highly productive commercialised dairy sector feeding high quality forage and grain. Separate beef cow herd, primarily grazing with feed supplements seasonally. Fast-growing beef steers/heifers finished in feedlots on grain. Dairy cows are a small part of the population.	Dairy	118	Average milk production of 6,700 kg/head/yr
	Non-Dairy	47	Includes beef cows, bulls, calves, growing steers/heifers, and feedlot cattle
***Western Europe*:** Highly productive commercialised dairy sector feeding high quality forage and grain. Dairy cows also used for beef calf production. Very small dedicated beef cow herd. Minor amount of feedlot feeding with grains.	Dairy	100	Average milk production of 4,200 kg/head /yr
	Non-Dairy	48	Includes bulls, calves, and growing steers/heifers
***Eastern Europe*:** Commercialised dairy sector feeding mostly forages. Separate beef cow herd, primarily grazing. Minor amount of feedlot feeding with grains.	Dairy	81	Average milk production of 2,550 kg/head /yr
	Non-Dairy	56	Includes beef cows, bulls, and young.
***Oceania*:** Commercialised dairy sector based on grazing. Separate beef cow herd, primarily grazing range lands of widely varying quality. Growing amount of feedlot feeding with grains. Dairy cows are a small part of the population.	Dairy	68	Average milk production of 1,700 kg/head /yr
	Non-Dairy	53	Includes beef cows, bulls, and young.
***Latin America*:** Commercialised dairy sector based on grazing. Separate beef cow herd grazing pastures and range lands. Minor amount of feedlot feeding with grains. Growing beef cattle comprise a large portion of the population.	Dairy	57	Average milk production of 800 kg/head /yr
	Non-Dairy	49	Includes beef cows, bulls, and young.

TABLE 4-3 (B) ENTERIC FERMENTATION METHANE EMISSION FACTORS FOR CATTLE			
Regional Characteristics	Cattle Type	Emissions Factor (kg CH_4/head /yr)	Comments
Asia: Small commercialised dairy sector. Most cattle are multi-purpose, providing draft power and some milk within farming regions. Small grazing population. Cattle of all types are smaller than those found in most other regions.	Dairy	56	Average milk production of 1,650 kg/head /yr
	Non-Dairy	44	Includes multi-purpose cows, bulls, and young.
Africa and Middle East: Commercialised dairy sector based on grazing with low production per cow. Most cattle are multi-purpose, providing draft power and some milk within farming regions. Some cattle graze over very large areas. Cattle of all types are smaller than those found in most other regions.	Dairy	36	Average milk production of 475 kg/head /yr
	Non-Dairy	32	Includes multi-purpose cows, bulls, and young.
Indian Subcontinent: Commercialised dairy sector based on crop by-product feeding with low production per cow. Most bullocks provide draft power and cows provide some milk in farming regions. Small grazing population. Cattle in this region are the smallest compared to cattle found in all other regions.	Dairy	46	Average milk production of 900 kg/head /yr
	Non-Dairy	25	Includes cows, bulls, and young. Young comprise a large portion of the population.
See the *Greenhouse Gas Inventory Reference Manual* for sources.			

STEP 2 ESTIMATING EMISSIONS FROM MANURE MANAGEMENT SYSTEMS

1 For each type of animal, enter the Emissions Factor for Manure Management in column D in kilograms per head per year. Use default data in the tables which follow or more precise locally available data.

Table 4-4 provides default emission factors for most livestock types with different values for developed and developing countries to reflect different conditions and typical practices. Factors are also provided for 3 different climates. Users should select the factors which best represent their conditions. For large countries it may be necessary to subdivide populations into more than one climate region. In that case the user can proceed with calculations in one of two ways.

a Develop an average emissions factor. For example:

If 25 per cent of sheep are in a temperate region and 75 per cent in a warm region, then

EF= (0.25 x 0.16) + (0.75 x 0.21) = 0.20 kg/head/yr

If users do develop and average emission factors, they should state what they have done and should document their sources.

b An alternative approach is to make extra copies of the Worksheet and complete one for each region for the manure portion, then add the results and enter the sum on the main Worksheet.

Swine, buffalo and cattle are the most important source of manure emissions and the most variable by region, therefore detailed emission factors are provided in a separate table.

2 Multiply the Number of Animals by the Emission Factor for Manure Management to give the Emissions from Manure Management in t/yr. Enter the results in column E.

TABLE 4-4
EMISSIONS FACTORS FOR MANURE MANAGEMENT
(KG CH_4 PER HEAD PER YEAR)

Livestock	Developed Countries			Developing Countries		
	Cool	Temp.[a]	Warm	Cool	Temp.[a]	Warm
Sheep	0.19	0.28	0.37	0.10	0.16	0.21
Goats	0.12	0.18	0.23	0.11	0.17	0.22
Camels	1.59	2.38	3.17	1.28	1.92	2.56
Horses	1.39	2.08	2.77	1.09	1.64	2.18
Mules and Asses	0.76	1.14	1.51	0.60	0.90	1.19
Poultry[b]	0.078	0.117	0.157	0.012	0.018	0.023

The range of estimates reflects cool to warm climates. Climate regions are defined in terms of annual average temperature as follows: Cool = less than 15°C; Temperate = 15°C to 25°C inclusive; and Warm = greater than 25°C. The Cool, Temperate and Warm regions are estimated using Methane Conversion Factors of 1%, 1.5% and 2%, respectively.

a Temp. = Temperate climate region.

b Chickens, ducks, and turkeys.

All estimates are ±20 percent.

Sources: Emission factors developed from: feed intake values and feed digestibilities used to develop the enteric fermentation emission factors (see Appendix A of the *Reference Manual* Chapter 4); MCF, and B_o values reported in Woodbury and Hashimoto (1993). All manure is assumed to be managed in dry systems, which is consistent with the manure management system usage reported in Woodbury and Hashimoto (1993).

TABLE 4-5
MANURE MANAGEMENT EMISSION FACTORS FOR CATTLE, SWINE, AND BUFFALO

Regional Characteristics	Livestock Type	Emissions Factor by Climate Region[a] (kg/head/year)		
		Cool	Temperate	Warm
North America: Liquid-based systems are commonly used for dairy and swine manure. Non-dairy manure is usually managed as a solid and deposited on pastures or ranges.	Dairy Cattle	36	54	76
	Non-Dairy Cattle	1	2	3
	Swine	10	14	18
Western Europe: Liquid / slurry and pit storage systems are commonly used for cattle and swine manure. Limited cropland is available for spreading manure.	Dairy Cattle	14	44	81
	Non-Dairy Cattle	6	20	38
	Swine	3	10	19
	Buffalo	3	8	17
Eastern Europe: Solid based systems are used for the majority of manure. About one-third of livestock manure is managed in liquid-based systems.	Dairy Cattle	6	19	33
	Non-Dairy Cattle	4	13	23
	Swine	4	7	11
	Buffalo	3	9	16
Oceania: Virtually all livestock manure is managed as a solid on pastures and ranges. About half of the swine manure is managed in anaerobic lagoons.	Dairy Cattle	31	32	33
	Non-Dairy Cattle	5	6	7
	Swine	20	20	20
Latin America: Almost all livestock manure is managed as a solid on pastures and ranges. Buffalo manure is deposited on pastures and ranges.	Dairy Cattle	0	1	2
	Non-Dairy Cattle	1	1	1
	Swine	0	1	2
	Buffalo	1	1	2
Asia: About half of cattle manure is used for fuel with the remainder managed in dry systems. Almost forty percent of swine manure is managed as a liquid. Buffalo manure is managed in drylots and deposited in pastures and ranges.	Dairy Cattle	7	16	27
	Non-Dairy Cattle	1	1	2
	Swine	1	4	7
	Buffalo	1	2	3
Africa: Almost all livestock manure is managed as a solid on pastures and ranges.	Dairy Cattle	1	1	1
	Non-Dairy Cattle	0	1	1
	Swine	0	1	2
Middle East: Over two-thirds of cattle manure is deposited on pastures and ranges. About one-third of swine manure is managed in liquid-based systems. Buffalo manure is burned for fuel or managed as a solid.	Dairy Cattle	1	2	2
	Non-Dairy Cattle	1	1	1
	Swine	1	3	6
	Buffalo	4	5	5
Indian Subcontinent: About half of cattle and buffalo manure is used for fuel with the remainder managed in dry systems. About one-third of swine manure is managed as a liquid.	Dairy Cattle	5	5	6
	Non-Dairy Cattle	2	2	2
	Swine	3	4	6
	Buffalo	4	5	5

a Cool climates have an average temperature below 15°C; temperate climates have an average temperature ranging from 15°C to 25°C inclusive; 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.

Note: Significant buffalo populations do not exist in North America, Oceania, or Africa.

See the *Greenhouse Gas Inventory Reference Manual* for sources.

STEP 3 ESTIMATING METHANE EMISSIONS FROM ENTERIC FERMENTATION AND MANURE MANAGEMENT

1 Sum emissions for Enteric Fermentation and Manure Management and enter the totals at the bottom of the Worksheet.

2 Add the two totals together to give Total Annual Emissions from Domestic Livestock.

Divide the final result by 1,000 to express it as gigagrams. Enter the result in column F.

4.3 Rice cultivation

Introduction

Anaerobic decomposition of organic material in flooded rice fields produces methane which escapes to the atmosphere primarily by transport through the rice plants. The amount of methane emitted is believed to be a function of rice species, number and duration of harvests, soil type and temperature, water management practices and fertiliser use.

Of the wide variety of sources for atmospheric CH_4, flooded rice fields are considered an important source. The IPCC estimated the global emission rate from flooded rice fields to be ranging from 20 to 150 teragrams per year. This is about 5-30 per cent of emissions from all sources. The figure is based mainly on field measurements of fluxes from paddy fields in the United States, Spain, China, Italy, India, Australia and Japan.

The measurements at various locations of the world show that there are temporal variations of CH_4 fluxes and that flux is critically dependent upon several factors including climate, characteristics of soils and paddy, and agricultural practices. About 90 per cent of the world's harvested area of rice fields is located in Asia. Of all the harvested area in Asia, 60 per cent is located in India and China.

Data sources

Data on cultivated rice area can be found by country and year in the annual United Nations Food and Agriculture Organization (FAO) Production Yearbooks (an annual publication containing annual agricultural statistics for generally the four most recent years). The most recent Production Yearbook (FAO, 1993) should be used, since each new issue updates previously published annual statistics. However, the annual cultivated areas presented in the Yearbooks combine all rice cultivation types, including wetland and upland areas.

ESTIMATING HARVESTED AREA

Harvested area is defined as the physical area under cultivation times the number of harvests. That is, if some areas are double cropped, they would be counted twice in harvested area.

A number of researchers have estimated the distribution of rice production by water management type by country. Table 4-6 summarises the results of one of these efforts.

See the *Greenhouse Gas Inventory Reference Manual* for a more detailed discussion of available data sources.

Methodology

Emissions of CH_4 from flooded rice fields can be calculated using a simple formula as follows:

CH_4 Flux (in Gg, by category)

= **Aggregate Emission Factor (kilograms per hectare-day, by category)**

x

Number of hectare-days of flooded cultivation (megahectare-days, by category)

From field experiments it is apparent that methane emissions from rice fields are affected by many factors. An expert group has recommended the factors for which there is sufficient information on both the emission factors and the hectare-days of cultivation. Including the available information in the present estimates of country-by-country emissions may improve the accuracy, but at present it is not certain which factors have the greatest effect on emissions.

The factors clearly identified by field experiments are:

- water level and its history in the growing season
- soil temperature
- fertiliser application
- soil type
- cultivar
- agricultural practices such as seeding or planting

Data show that higher temperatures, continuously flooded fields, some types of organic fertilisers, and certain cultivars lead to higher emissions compared to rice grown at lower temperatures with intermittent or managed irrigation in which the fields are not continuously inundated and with the use of chemical fertilisers.

At present there are insufficient data to incorporate most of these factors. Nonetheless the estimates can be improved substantially by incorporating the current knowledge on the first two factors - water management regime and temperature (the temperature is in ^{o}C.) For some countries the effects of organic and mineral fertiliser can be included. Inclusion of the remaining factors may be possible within one to two years.

Data on rice agriculture under different water management regimes may be available from most of the rice producing countries. Therefore the basic method for estimating emissions from each country includes estimates for the three water regimes, i.e. continuously flooded[1], intermittently flooded[2] and dry[3] rice agriculture. The dry category does not produce significant emissions and can be excluded from methane calculations.

Individual countries may use as much detail as can be scientifically justified based on laboratory and field experiments and theoretical calculations to arrive at the estimate of emissions from flooded rice fields. These details should be incorporated into subcategories under each of the two main water management regime categories so that they can be compared with equivalent data from other countries.

[1] Fields inundated for the duration of the growing season.

[2] Fields not inundated for the duration of the growing season.

[3] Fields seldom flooded during the growing season.

Completing the Worksheet

Use WORKSHEET 4-2 METHANE EMISSIONS FROM FLOODED RICE FIELDS at the end of this section to enter your data. Table 4-6 gives default data for the distribution of rice growing areas and water management types throughout the world.

STEP 1 ESTIMATING THE HARVESTED AREA AND DAYS OF CULTIVATION

1 Enter the Harvested Area by water management regime (in millions of hectares or megahectares) in column A.

Harvested area is defined as land under cultivation times the number of harvests per year. Area cultivated under upland or dry conditions is excluded from methane calculations. Table 4-6 provides some default information which can be used if data are not locally available. Note that the data for area harvested provided in Table 4-6 is expressed in units of thousands of hectares. If these data are used they must first be converted to megahectares.

2 Enter the Season Length for each category (in days) in column B.

Default values are provided in Table 4-6 and can be used if more detailed data are not locally available. The default season length is the weighted average of all growing seasons.

3 For each category, multiply Harvested Area (column A) by Season Length (column B) to give the megahectare-Days Flooded and enter this figure in column C.

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary.

SEASON LENGTH

In these calculations, **season length** is defined as the **average** length of time, in days, from seeding or transplanting until harvest – for the country, region or category being calculated. These **average** values may be lower than some published crop calendar data, which may account for the full growing season, including staggered crops.

TABLE 4-6 DEFAULT ACTIVITY DATA - HARVESTED RICE					
Country	1990 Area (1000s ha)	Season Length (days)	Continuously Flooded (%)	Dry (%)	Intermittently Flooded (%)
AMERICAS					
USA	1114	123	100	0	0
Belize	2	139	10	90	0
Costa Rica	53	103	10	90	0
Cuba	150	139	100	0	0
Dominican Republic	93	103	98	2	0
El Salvador	15	123	10	90	0
Guatemala	15	139	10	90	0
Haiti	52	123	40	60	0
Honduras	19	123	10	90	0
Jamaica	0	123	40	60	0
Mexico	123	130	41	59	0
Nicaragua	48	123	10	90	0
Panama	92	103	5	95	0
Puerto Rico	0	123	75	25	0
Trinidad & Tobago	5	103	45	55	0
Argentina	103	121	100	0	0
Bolivia	110	101	25	75	0
Brazil	4450	101	18	76	6
Chile	35	121	79	21	0
Columbia	453	124	53	47	0
Equator	266	100	40	10	50
Guyana	68	123	95	5	0

TABLE 4-6 (CONTINUED) DEFAULT ACTIVITY DATA - HARVESTED RICE					
Country	1990 Area (1000s ha)	Season Length (days)	Continuously Flooded (%)	Dry (%)	Intermittently Flooded (%)
AMERICAS (CONT.)					
Paraguay	34	101	50	50	0
Peru	185	167	84	16	0
Surinam	58	123	100	0	0
Uruguay	108	138	100	0	0
Venezuela	119	103	90	10	0
ASIA					
Brunei	1	82	79	21	0
Hong Kong	0	123	100	0	0
Syria	0	123	100	0	0
Turkey	52	123	100	0	0
India	42321	107	53	15	32
Pakistan	103	103	100	0	0
Bangladesh	10303	132	14	14	72
Myanmar	4774	139	42	15	43
Nepal	1440	90	29	4	67
Afghanistan	173	103	100	0	0
Bhutan	25	169	21	15	64
China	33265	115	93	2	5
Indonesia	10403	110	78	15	7
Iran	570	103	100	0	0
Iraq	78	123	100	0	0
Japan	2073	123	96	4	0
Malaysia	2073	109	64	12	24
Philippines	3413	98	54	12	34
Sri Lanka	793	122	65	7	28
Taiwan	700	119	97	3	0
Thailand	9878	123	22	12	66
Kampuchea	1800	134	34	27	39
Laos	625	123	11	49	40
Vietnam	6069	119	65	7	28
N Korea	673	103	67	13	20
S Korea	1237	103	91	1	8

REFLECTING MORE DETAIL

If you have the necessary data, you can sub-divide your data further to account for different fertilising practices. Furthermore, if regional variations in temperature, cultivation practices, etc. justify it, calculations can be done at sub-national regional level. In either case you should use extra copies of the Worksheet and label them clearly by subcategory or region. You should then aggregate the results to provide a national summary table from the basic categories described in the method. This is done by summing *Harvested Area, megahectare-days* and *CH_4 Emissions* from the subsidiary worksheets. Weighted averages by category can be derived for:

- **Season Length** in days (divide megahectare-days by harvested area in Mha)
- **Emission Factor** (divide CH_4 Emissions by megahectare-days)

TABLE 4-6 (CONTINUED) DEFAULT ACTIVITY DATA - HARVESTED RICE					
Country	1990 Area (1000s ha)	Season Length (days)	Continuously Flooded (%)	Dry (%)	Intermittently Flooded (%)
EUROPE					
Albania	2	123	100	0	0
Bulgaria	11	103	100	0	0
France	20	139	100	0	0
Greece	15	103	100	0	0
Hungary	11	123	100	0	0
Italy	208	102	100	0	0
Portugal	33	123	100	0	0
Romania	37	123	100	0	0
Spain	81	103	100	0	0
Former USSR	624	103	100	0	0
Former Yugoslavia	8	123	100	0	0
PACIFIC					
Australia	97	128	100	0	0
Fiji	13	81	50	50	0
Solomon Islands	0	102	38	62	0
Papua/New Guinea	0	102	38	62	0
AFRICA					
Algeria	1	138	100	0	0
Angola	18	121	100	0	0
Benin	7	123	10	90	0
Burkina Faso	19	123	89	11	0
Burundi	12	167	25	75	0
Cameroon	15	103	25	75	0
C African Republic	10	123	25	75	0
Chad	39	123	25	75	0
Comoros	13	100	100	0	0
Congo	4	121	25	75	0
Egypt	427	123	100	0	0
Gabon	0	121	25	75	0
Gambia	14	123	90	10	0
Ghana	85	139	24	76	0
Guinea Bissau	57	123	25	75	0
Guinea	608	123	8	47	45
Ivory Coast	583	123	6	87	7
Kenya	15	139	25	75	0
Liberia	168	123	0	94	6
Madagascar	1135	167	35	19	46
Malawi	29	137	25	75	0
Mali	222	123	25	75	0
Mauritania	14	123	100	0	0
Morocco	6	138	100	0	0
Mozambique	109	121	25	75	0
Niger	29	102	35	65	0

TABLE 4-6 (CONTINUED)
DEFAULT ACTIVITY DATA - HARVESTED RICE

Country	1990 Area (1000s ha)	Season Length (days)	Continuously Flooded (%)	Dry (%)	Intermittently Flooded (%)
Nigeria	1567	103	28	55	17
Rwanda	3	167	25	75	0
Senegal	73	103	25	75	0
Sierra Leone	339	139	1	67	32
Somalia	5	103	50	50	0
South Africa	1	167	100	0	0
Sudan	1	103	50	50	0
Swaziland	0	167	25	75	0
Tanzania	375	137	10	26	64
Togo	21	139	4	96	0
Uganda	37	137	25	75	0
Zaire	393	101	5	90	5
Zambia	11	121	25	75	0
Zimbabwe	0	121	25	75	0

TABLE 4-7
SEASONAL AVERAGE EMISSION FACTORS CORRECTED FOR AVERAGE TEMPERATURE

Growing Season Average Temperature	Emission Factor kg methane/ha-days	
	Continuously Flooded	Intermittently Flooded
15	2.91	1.75
16	3.09	1.85
17	3.28	1.97
18	3.48	2.09
19	3.68	2.21
20	3.91	2.34
21	4.14	2.94
22	4.39	2.64
23	4.66	2.80
24	4.94	2.97
25	5.24	3.15
26	5.56	3.34
27	5.90	3.54
28	6.25	3.75
29	6.63	3.98
30	7.03	4.22
31	7.46	4.48
32	7.91	4.75
33	8.39	5.03
34	8.90	5.34
35	9.44	5.66

STEP 2 ESTIMATING METHANE EMISSIONS BY WATER MANAGEMENT REGIME

EMISSION FACTORS

National experts are encouraged to use locally available measurement data to develop more accurate emission factors reflecting conditions in their countries, if possible, rather than using the default values provided. If this is done, experts must ensure that alternative factors are based on a sufficient number of measurements to capture the variability from day to day and day to night, and to produce a statistically representative seasonal average value.

1 Enter average Emission Factors by water management regime (in kilograms per hectare-day) in column D.

If emissions factors based on local measurement data are available, these should be used and documented. If data are available in grams per square metre-day (g/m^2-day), the values should be multiplied by 10 to convert to kilograms per hectare-day (kg/ha-day). Default values are provided in Table 4-7 by water management regime and average temperature. Information on average temperature can be used in either of two ways:

- You can select the temperature which reflects the average for the growing season of all rice grown in the country and enter this national average.
- In larger countries, you can sub-divide the area harvested into sub-regions with different growing temperatures and use an appropriate emission factor for each sub-region. When you do this, you should use multiple copies of the Worksheet 4-2.

2 For each category, multiply megahectare-days (column C) by the Emission Factor (column D) to give CH_4 Emissions in gigagrams. Enter the result in column E.

3 Sum emissions and enter the total at the bottom of column E.

4.4 Prescribed Burning of Savannas

Introduction

Savannas are tropical and subtropical formations with continuous grass coverage. The growth of savannas is controlled by alternating wet and dry seasons: most of the growth occurs during the wet season. Man-made and/or natural fires frequently occur during the dry season, resulting in nutrient recycling and regrowth. Large scale burning takes place primarily in the humid savannas because the arid savannas lack sufficient grass cover to sustain fire. Savannas are burned every one to four years on average, with the highest frequency in the humid savannas of Africa.

The burning of savannas results in instantaneous emissions of carbon dioxide. However, because the vegetation regrows between the burning cycles, the carbon dioxide released to the atmosphere is reabsorbed during the next vegetation growth period. Therefore, this *Workbook* assumes that CO_2 net emissions are zero.

The burning of savannas also releases gases other than CO_2, including methane, carbon monoxide, nitrous oxide and oxides of nitrogen. Unlike CO_2 emissions these are net anthropogenic emissions and should be accounted for.

DEGRADED SAVANNAS

Although the default assumption is that biomass burned on savannas regrows in a short period, this may not always be the case. Sometimes savannas are burned too often, or for other reasons fail to recover completely. Over time savannas can degrade significantly as a result of human intervention. In this case there will be a long-term loss of carbon in aboveground biomass and soils. If this is occurring, the annual carbon loss should be accounted for, if possible, in addition to the information requested in the *Workbook*.

Data sources

There are no routinely published data on the amount of savanna burned, but several assessment papers have been published. The *FAO Forest Resource Assessment 1990: Tropical Countries* (FAO 1993) provides country estimates of savanna (grassland) area and the *Greenhouse Gas Inventory Reference Manual* provides additional references.

Methodology

The non-CO_2 trace gas emissions from savanna burning may be estimated through a series of simple calculations using locally available data or defaults provided in the tables provided in this *Workbook*.

First the quantity of biomass that actually burns is calculated by multiplying area of savanna burned by average biomass density and by the fraction of exposed biomass which actually burns.

Second, carbon released is calculated multiplying quantity of biomass burned by fraction oxidised and then by carbon fraction.

NON-METHANE VOLATILE ORGANIC COMPOUNDS

NMVOCs are emitted in significant quantities from biomass burning. These emissions should be estimated using the same approach provided for other non-CO_2 gases. However, the default information has not yet been developed to include this class of gases in the *Workbook*. This is an area to be considered in future improvements to the *Guidelines*.

FRACTIONS

In order to determine the amount of savanna biomass that actually oxidises to release carbon to the atmosphere, several *fractions* must be applied sequentially. To start with, the quantity of biomass exposed to fire is calculated by multiplying the area of savanna burned in the inventory year by the average biomass density (in tonnes of dry matter per hectare). The fractions are then applied as follows.

Fraction which Actually Burns

Under normal open burning conditions all biomass in each hectare does not actually burn. The *Fraction which Actually Burns* (generally 0.80 - 0.85 but may be higher in very dry regions) is applied to derive the kilotonnes of dry matter which actually burn.

Fraction Oxidised

This next fraction to be applied expresses the biomass that oxidises. Not all of the burning biomass oxidises - a small fraction may remain as charcoal. The fraction oxidised is usually 0.8 to 1.0.

Carbon Fraction

The last fraction to be applied determines the amount of carbon that is released from the fraction of biomass which has oxidised.

The second calculation can be greatly improved by first dividing the quantity of biomass burned into living and dead fractions. The calculation is then carried out for each of these fractions using different fractions oxidised and carbon contents for the living and dead fractions.

Third, several ratios are applied to total carbon released to derive estimates of non-CO_2 trace gas emissions, as follows:

- a nitrogen-carbon ratio is applied to estimate total nitrogen content
- ratios for CH_4 and CO as fractions of total carbon
- ratios of N_2O and NO_x as fractions of total nitrogen

The resulting estimates of emissions are converted to total weight (i.e. from CH_4 as C to CH_4 total) using standard factors.

One country may possess more than one type of savanna with different characteristics; burns may vary in efficiency; and burns may take place at different times during the dry season, causing the burning to vary with the state of the vegetation (such as the moisture content and whether the biomass is alive or dead).

If data are locally available savanna burned should be subdivided into relevant subcategories reflecting these variations and entered into the worksheet. If you are relying on the default values in this *Workbook* you will only be able to carry out calculations at a national level.

Completing the Worksheet

STEP 1 ESTIMATING TOTAL BIOMASS THAT ACTUALLY BURNS

Use WORKSHEET 4-3 PRESCRIBED BURNING OF SAVANNAS at the end of this section to record inventory data. You should do this for a single national average category or subdivide if data are locally available for each relevant subcategory of savanna.

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary

1 For each category of savanna, enter the Area Burned (in kilohectares) in column A.

 If possible use locally available data for hectares of savanna burned annually. If this is not possible, a crude default approach is to determine the total savanna area and multiply by typical regional defaults for percent burned annually from Table 4-8 (below).

TABLE 4-8
REGIONAL SAVANNA STATISTICS

Region	Fraction of Total Savanna Burned Annually	Aboveground Biomass Density (t dm/ha)	Fraction of Biomass Actually Burned	Fraction of Aboveground Biomass that is Living
Tropical America	0.50	6.6 ±1.8		
Tropical Asia	0.50	4.9		
Tropical Africa	0.75	6.6 ±1.6		
Sahel zone	0.05-0.15	0.5-2.5*	0.95	0.20
North Sudan zone	0.25-0.50	2-4*	0.85	0.45
South Sudan zone	0.25-0.50	3-6*	0.85	0.45
Guinea zone	0.60-0.80	4-8*	0.90-1.0	0.55
Australia	0.05-0.70	2.1-6		

Regional defaults are for seasonal average densities which should be used for emissions calculations. Values marked with * are maximum, season end densities which are appropriate defaults for these very dry sub-regions.

Note: These are ecological zones that do not correspond directly to areas with political boundaries of the same name. For example, the North and South Sudan Zones include countries other than Sudan and run East-West across the African continent.

See the *Greenhouse Gas Inventory Reference Manual* for sources of these figures.

CATEGORIES OF SAVANNAS

A number of users of the draft *Guidelines*, particularly in Africa, have suggested that savannas should be divided into woody savannas and grasslands if possible. For woody savannas, the aboveground biomass densities prior to burning would be higher and the fraction oxidised should be lower, as much of the standing woody biomass would not be burned. Other subcategories by region, time of burning, etc. may also be useful.

2 For each category of savanna, enter the Biomass Density of the Savanna (in tonnes of dry matter per hectare) in column B. Table 4-8 provides available summary information by region which can be used as default data.

3 Multiply the Area Burned by the Biomass Density of the Savanna to give the Total Biomass Exposed to Burning (in gigagrams of dry matter, which is the same as kilotonnes dm). Enter the result in column C.

4 Enter the Fraction of Biomass Actually Burned in column D.

 Use locally available data if available. You can use a general default figure in the range 0.80 - 0.85. Some specific values for African sub-regions are given in Table 4-8.

5 Multiply Total Biomass Exposed to Burning (column C) by the Fraction Actually Burned (column D) to give the Quantity Actually Burned. Enter the results in column E.

STEP 2 ESTIMATING THE PROPORTIONS OF LIVING AND DEAD BIOMASS

1 Enter the Fraction of Living Biomass burned in column F.

Some default figures are in Table 4-8 for specific sub-regions in Africa. In other regions users must provide these values. If no information is available, users can do the calculation using "combined values" (see the box in the margin of this page).

2 Multiply the Quantity Actually Burned by the Fraction of Biomass Living to give the quantity of Living Biomass Burned (in gigagrams of dry matter). Enter the result in column G.

3 Subtract the Living Biomass Burned from the Quantity of Biomass Actually Burned to give the quantity of Dead Biomass Burned (in gigagrams of dry matter). Enter the result in column H.

COMBINED VALUES

From this point on in the worksheet, each original category is split into two parts - living and dead - for which calculations are made separately. Each row in the worksheet splits into living and dead rows for columns I through J. If users are not able to report living and dead fractions, the default calculation can be done using "combined" values from Table 4-9.

TABLE 4-9
GENERAL DEFAULT VALUES

	Fraction Oxidised	Carbon Fraction
Living Fraction	0.80	0.45
Dead Fraction	1.0	0.40
Combined	0.90	0.45

STEP 3 ESTIMATING THE TOTAL CARBON RELEASED

1 For each category of savanna, enter the Fraction Oxidised for *living* and *dead* biomass. Enter the results in the appropriate boxes in column I. Default figures are in Table 4-9.

2 For each category of savanna multiply the Living Biomass Burned by the Fraction Oxidised for living biomass. **Also,** multiply Dead Biomass Burned by the Fraction Oxidised for dead biomass. Enter the results, in gigagrams of dry matter, in the appropriate boxes in column J.

3 For each category of savanna, living and dead, enter the Carbon Fraction (of dry matter) of living and dead biomass in column K. Default figures are in Table 4-9.

4 Multiply the Total Biomass Burned by the Carbon Fraction for each category of savanna, living and dead, to give the Total Carbon Released. Enter the results in column L in gigagrams of carbon.

5 Add the totals in column L and enter the result in the Total box at the bottom of the column. Carry the result forward to column L at the start of sheet 3 on the next page.

STEP 4 ESTIMATING NON-CO_2 TRACE GAS EMISSIONS FROM SAVANNA BURNING

1 Enter the Nitrogen-Carbon Ratio in column M.

If no data specific to biomass type are locally available, use the general default value for savannas, which is 0.006.

2 Multiply Total Carbon Released (column L) by the Nitrogen-Carbon Ratio to give the Total Nitrogen Content (in gigagrams of Nitrogen). Enter the result in the appropriate box in column N.

3 For each gas - methane (CH_4), carbon monoxide (CO), nitrous oxide (N_2O) and nitrogen oxides (NO_x) - enter an Emission Ratio in column O.

Table 4-10 shows the default ratios.

TABLE 4-10
EMISSION RATIOS AND RANGES FOR SAVANNA BURNING CALCULATIONS

Compound	Default value	Range
CH_4	0.004	0.002 - 0.006
CO	0.06	0.04 - 0.08
N_2O	0.007	0.005 - 0.009
NO_x	0.121	0.094 - 0.148

Note: Ratios for carbon compounds are mass of carbon released as CH_4 or CO (in units of C) relative to mass of total carbon released from burning (in units of C); those for the nitrogen compounds are expressed as the ratios of mass of nitrogen compounds released relative to the total mass of nitrogen released from the fuel.

See the *Greenhouse Gas Inventory Reference Manual* for sources.

4 Multiply Total Carbon Released (column L) (for CH_4 and CO), or Total Nitrogen Content (column N) (for N_2O and NO_x) by the emissions ratios in column O to give the total emissions for each gas. Enter the results in column P.

STEP 5 CONVERT EMISSIONS OF CARBON AND NITROGEN INTO METHANE, CARBON MONOXIDE, NITROUS OXIDE AND NITROGEN OXIDE EMISSIONS.

1 Multiply the emissions of each gas expressed as C or N by the appropriate Conversion Ratio[4] in column Q to give the Emissions from Savanna Burning for each gas emitted. Enter the results in column R.

[4] The molecular weight ratios given above for the emitted gases are with respect to the weight of nitrogen or carbon in the molecule. Thus for N_2O the ratio is 44/28 and for NO_X it is 46/14. NO_2 has been used as the reference molecule for NO_X.

4.5 Field Burning of Agricultural Residues

Introduction

Large quantities of agricultural residues are produced from farming systems world-wide. Burning of crop residues in the fields is a common agricultural practice, particularly in developing countries. It has been estimated that as much as 40 per cent of the residues produced in developing countries may be burned in fields, while the percentage is lower in developed countries. It is important to note that some crop residues are removed from the fields and burned as a source of energy, especially in developing countries. Emissions from this type of burning are calculated in the Energy module of this *Workbook*. Users should ensure that residue burning is properly allocated to these two components and not double counted.

This submodule deals exclusively with emissions of methane, carbon monoxide, nitrous oxide and nitrogen oxides from crop residues. In this *Workbook*, field burning of crop residues is not treated as a net source of carbon dioxide because it is assumed that the carbon released to the atmosphere is reabsorbed during the next growing season. However crop residue burning is a significant net source of emissions of methane, carbon monoxide, nitrous oxide and nitrogen oxides.

Data sources

Annual crop production statistics by country for most of the crops from which residues are burned may be found in FAO Production Year Books (e.g. FAO, 1991). Crop specific data for each country on ratios of residue to crop production, fraction of residue burned, dry matter content of residue and carbon and nitrogen contents of residue should be provided by individual countries if available. Table 4-11 *Selected Crop Residue Statistics* shows default data for crop residues.

TABLE 4-11 **SELECTED CROP RESIDUE STATISTICS**				
Product	Residue / Crop Ratio	Dry Matter Fraction	Carbon Fraction	Nitrogen-Carbon Ratio
Wheat	1.3	0.78-0.88	0.4853	0.012
Barley	1.2	0.78-0.88	0.4567	
Maize	1	0.30-0.50	0.4709	0.02
Oats	1.3			
Rye	1.6			
Rice	1.4	0.78-0.88	0.4144	0.014
Millet	1.4			0.016
Sorghum	1.4			0.02
Pea	1.5			
Bean	2.1			
Soya	2.1			0.05
Potatoes	0.4	0.30-0.60	0.4226	
Feedbeet	0.3	0.10-0.20[1]	0.4072	
Sugarbeet	0.2	0.10-0.20[1]	0.4072	
Jerusalem artichoke	0.8			
Peanut	1			

Note: Crop statistics in this table are not complete. For values not specified you should use values for the most similar crop type as defaults.

See the *Greenhouse Gas Inventory Reference Manual* for sources.

1 These statistics are for beet leaves.

Completing the Worksheet

STEP 1 CALCULATING THE AMOUNT OF RESIDUE

Use WORKSHEET 4-4 FIELD BURNING OF AGRICULTURAL RESIDUES to enter data for this submodule.

1 Specify the important crops which produce residues burned in fields and enter these as categories on the Worksheet.

2 For each type of crop, enter Annual Production in gigagrams, which is the same as kilotonnes, of crop product in column A.

3 Enter the Residue to Crop Ratio for each crop type in column B. Use Table 4-11 above if there are no local statistics.

4 Multiply the Annual Production of each crop by the Residue to Crop Ratio to give the Quantity of Residue. Enter the result in column C.

STEP 2 ESTIMATING THE AMOUNT OF DRY RESIDUE

1 Enter Dry Matter Fraction for each crop type in column D.

Default values for some crop types are shown in Table 4-11.

2 Multiply the Quantity of Residue by the Dry Matter Fraction to give the Quantity of Dry Residue in gigagrams of dry matter. Enter the result in column E.

STEP 3 ESTIMATING TOTAL BIOMASS BURNED

1 Enter the Fraction Burned in Fields for each crop type in column F.

Values should reflect an average of practices for the individual country. No default data are available.

2 Enter the Fraction Oxidised for each crop type in column G (default value 0.90).

3 Multiply the Quantity of Dry Residue by the Fraction Burned in Fields and the Fraction of Biomass Oxidised to give the Total Biomass Burned (in gigagrams of dry matter). Enter the result in column H.

STEP 4 CALCULATING THE TOTAL CARBON RELEASED

1 Enter the Carbon Fraction of each residue in column I.

Default values for some crop types are shown in Table 4-11. If no other information is available, use the general default for live biomass, which is 0.45.

2 Multiply the Total Biomass Burned by the Carbon Fraction of each residue to give the Total Carbon Released in gigagrams of carbon. Enter the results in column J.

3 Add the totals for each crop type in column J and enter the result in the Total box at the bottom of the column.

STEP 5 ESTIMATING TOTAL NITROGEN RELEASED

1 Enter the Nitrogen-Carbon Ratio for each crop type in column K.

The general default Nitrogen-Carbon ratio for crops is 0.01- 0.02. Some specific values for individual crops are given in Table 4-11.

2 Multiply the Total Carbon Released (column J) by the Nitrogen-Carbon Ratio (column K) to give the Total Nitrogen Released. Enter the result in column L.

3 Add the Total Nitrogen Released for each crop type and enter the result in the Total box at the bottom of column L.

STEP 6 ESTIMATING NON-CO_2 TRACE GAS EMISSIONS

1 Enter Emission Ratios in the relevant boxes in column M. Table 4-12 shows default emission ratios and ranges.

TABLE 4-12
DEFAULT EMISSION RATES FOR AGRICULTURAL RESIDUE BURNING CALCULATIONS

	Ratios	
Gas	*Default*	*Range*
CH_4	0.005	0.003-0.007
CO	0.06	0.04-0.08
N_2O	0.007	0.005-0.009
NO_x	0.121	0.094-0.148

Note: Ratios for carbon compounds are mass of carbon released as CH_4 or CO (in units of C) relative to mass of total carbon released from burning (in units of C); those for the nitrogen compounds are expressed as the ratios of mass of nitrogen compounds released relative to the total mass of nitrogen released from the fuel.

See the *Greenhouse Gas Inventory Reference Manual* for sources.

2 Multiply Carbon Released (Total from column J) by the Emission Ratios for CH_4 or CO (column M) to give the Emissions of Carbon as methane and carbon monoxide. Enter the results in the appropriate boxes in column N.

3 Multiply Nitrogen Released (Total from column L) by the Emission Ratios for N_2O or NO_x (column M) to give the Emissions of Nitrogen as nitrous oxide and nitrogen oxides. Enter the results in the appropriate boxes in column N.

4 For each gas, multiply by the Conversion Ratio[5] in column O to give the amount of Emissions from Burning Agricultural Residues. Enter the results, in gigagrams of each gas, in the appropriate boxes in column P.

[5] The molecular weight ratios given above for the emitted gases are with respect to the weight of nitrogen or carbon in the molecule. Thus for N_2O the ratio is 44/28 and for NO_X it is 46/14. NO_2 has been used as the reference molecule for NO_X.

MODULE	AGRICULTURE					
SUBMODULE	METHANE EMISSIONS FROM DOMESTIC LIVESTOCK ENTERIC FERMENTATION AND MANURE MANAGEMENT					
WORKSHEET	4-1					
SHEET	1 OF 1					
Livestock Type	A Number of Animals (1000s)	B Emissions Factor for Enteric Fermentation (kg/head/year)	C Emissions from Enteric Fermentation (t/year)	D Emissions Factor for Manure Management (kg/head/year)	E Emissions from Manure Management (t/year)	F Total Annual Emissions from Domestic Livestock (Gg)
			C=(AxB)		E=(AxD)	F=(C+E)/1000
Dairy Cattle						
Non-Dairy Cattle						
.Buffalo						
Sheep						
Goats						
Camels						
Horses						
Mules & Asses						
Swine						
Poultry						
		Totals				

MODULE	AGRICULTURE				
SUBMODULE	METHANE EMISSIONS FROM FLOODED RICE FIELDS				
WORKSHEET	4-2				
SHEET	1 OF 1				
	STEP 1			STEP 2	
Water Management Regime	A Harvested Area (Mha)	B Season Length (days)	C Megahectare-Days (Mha-days)	D Emission Factor (kg/ha-day)	E CH_4 Emissions by Water Management (Gg)
			C=(AxB)		E=(CxD)
Continuously Flooded					
Intermittently Flooded					
Totals					

MODULE	AGRICULTURE						
SUBMODULE	PRESCRIBED BURNING OF SAVANNAS						
WORKSHEET	4-3						
SHEET	1 OF 3						
STEP 1					STEP 2		
A Area Burned by Category (specify) (k ha)	B Biomass Density of Savanna (t dm/ha)	C Total Biomass Exposed to Burning (Gg dm)	D Fraction Actually Burned	E Quantity Actually Burned (Gg dm)	F Fraction of Living Biomass Burned	G Quantity of Living Biomass Burned (Gg dm)	H Quantity of Dead Biomass Burned (Gg dm)
		C=(AxB)		E=(CxD)		G=(ExF)	H=(E-G)

MODULE	AGRICULTURE		
SUBMODULE	PRESCRIBED BURNING OF SAVANNAS		
WORKSHEET	4-3		
SHEET	2 OF 3		
STEP 3			
I Fraction Oxidised of living and dead biomass	J Total Biomass Oxidised (Gg dm)	K Carbon Fraction of Living & Dead Biomass	L Total Carbon Released (Gg C)
	Living: J=(GxI) *Dead:* J=(HxI)		L=(JxK)
Living			
Dead			
Living			
Dead			
Living			
Dead			
Living			
Dead			
Living			
Dead			
Living			
Dead			
Living			
Dead			
		Total	

MODULE	AGRICULTURE
SUBMODULE	PRESCRIBED BURNING OF SAVANNAS
WORKSHEET	4-3
SHEET	3 OF 3

STEP 4					STEP 5	
L Total Carbon Released (Gg C)	M Nitrogen-Carbon Ratio	N Total Nitrogen Content (Gg N)	O Emissions Ratio	P Emissions (Gg C **or** Gg N)	Q Conversion Ratio	R Emissions from Savanna Burning (Gg)
		N=(LxM)		P=(LxO)		R=(PxQ)
					16/12	CH_4
					28/12	CO
				P=(NxO)		R=(PxQ)
					44/28	N_2O
					46/14	NO_x

MODULE	**AGRICULTURE**
SUBMODULE	**FIELD BURNING OF AGRICULTURAL RESIDUES**
WORKSHEET	**4-4**
SHEET	**1 OF 3**

	STEP 1			STEP 2		STEP 3		
Crops (specify locally important crops)	A Annual Production (Gg crop)	B Residue to Crop Ratio	C Quantity of Residue (Gg biomass)	D Dry Matter Fraction	E Quantity of Dry Residue (Gg dm)	F Fraction Burned in Fields	G Fraction Oxidised	H Total Biomass Burned (Gg dm)
			C=(AxB)		E=(CxD)			H=(ExFxG)
							Total:	

	MODULE	AGRICULTURE		
	SUBMODULE	FIELD BURNING OF AGRICULTURAL RESIDUES		
	WORKSHEET	4-4		
	SHEET	2 OF 3		
	STEP 4		STEP 5	
	I Carbon Fraction of Residue	J Total Carbon Released (Gg C)	K Nitrogen-Carbon Ratio	L Total Nitrogen Released (Gg N)
		J=(HxI)		L=(JxK)
Total:				

MODULE	**AGRICULTURE**			
SUBMODULE	**FIELD BURNING OF AGRICULTURAL RESIDUES**			
WORKSHEET	**4-4**			
SHEET	**3 OF 3**			
		STEP 6		
	M Emission Ratio	N Emissions (Gg C **or** Gg N)	O Conversion Ratio	P Emissions from Field Burning of Agricultural Residues (Gg)
		N=(JxM)		P=(NxO)
CH_4			16/12	
CO			28/12	
		N=(LxM)		P=(NxO)
N_2O			44/28	
NO_x			46/14	

MODULE 5
LAND USE CHANGE & FORESTRY

LAND USE CHANGE & FORESTRY

5 LAND USE CHANGE & FORESTRY

5.1 Introduction

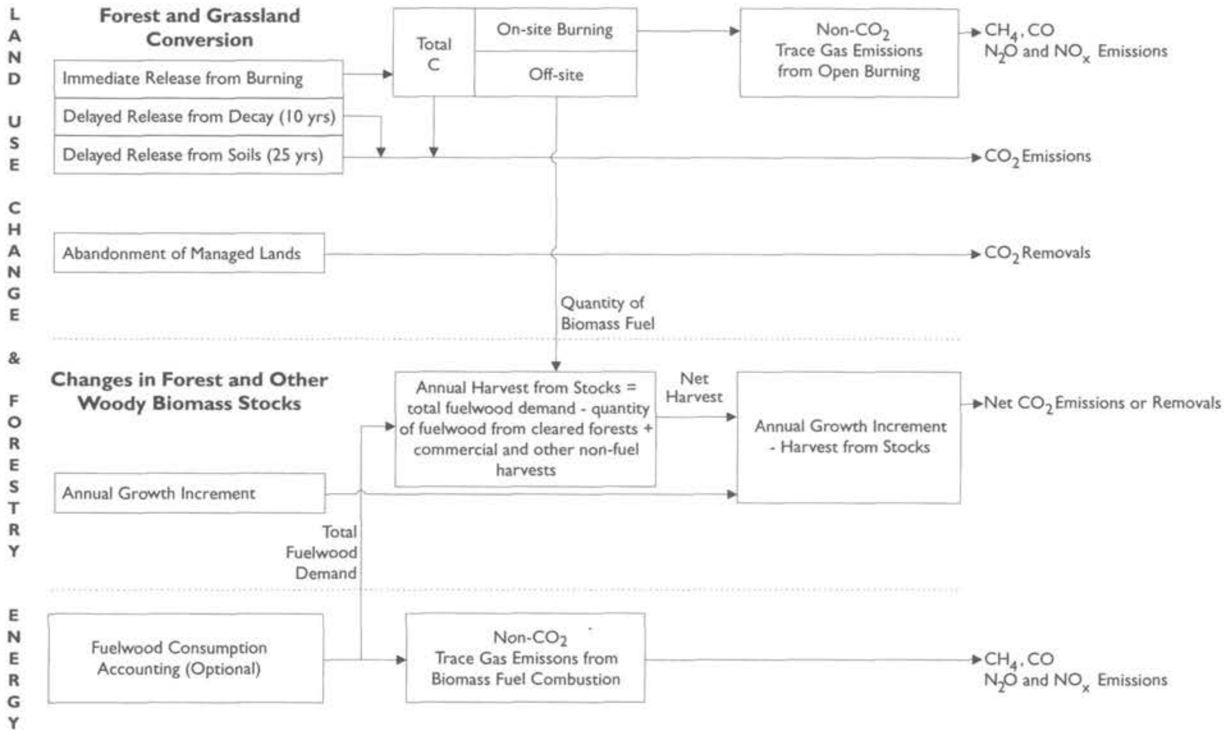
The priority calculations of emissions from land use change and forestry focus upon three activities which are sources or sinks of carbon dioxide. One of these activity types is also a source of other non-CO_2 trace gas (CH_4, CO, N_2O, and NO_x) emissions, and these are also calculated here.

On a global scale the most important land-use changes and management practices that result in CO_2 emissions and uptake are:

- changes in forest and other woody biomass stocks
- forest and grassland conversion
- abandonment of managed lands

The immediate release of non-CO_2 trace gases from the burning associated with forest/grassland conversion is also calculated. These calculations are very similar to calculations of non-CO_2 trace gas emissions of other major types of biomass burning: biomass fuel combustion (in the Energy module) and burning of savannas and agricultural residues (in the Agriculture module).

FIGURE 1: Relationships Among Categories



The diagram above illustrates the relationships between the categories in this module and also with biomass fuel combustion in the Energy module. The key linkages are:

1. To estimate CO_2 emissions from forest/grassland conversion it is only necessary to know the total amount of biomass burned as a result of that land conversion in the particular year of the inventory.

2. Total biomass burned must be divided into *on-site* and *off-site* (fuelwood) portions for other reasons:

   - the type of burning affects the emissions of non-CO_2 trace gases such as methane, and therefore different emissions factors may be applied to open burning (on-site) and to fuelwood use (off-site)

   - the amount of fuelwood removed during forest conversion must be subtracted from total fuelwood consumed in order to determine net harvests from woody biomass stocks.

3 Countries which have good statistics on direct harvesting of all types of woody biomass and all uses of biomass for fuel should use these data. In many countries, significant amounts of wood removed from forests and other biomass stocks (primarily for domestic use) are not included in commercial harvest statistics. These countries can use the optional Fuelwood Consumption Accounting approach in the Energy module. This is based on household and other fuel consumption surveys, scaled to population, in order to estimate annual demand for fuelwood and other traditional fuels. This information can be used **instead of or in combination with** commercial harvest and sales statistics.

Fuelwood consumption information is used in two ways:

- for estimating non-CO_2 trace gas emissions from biomass fuel combustion
- total wood consumption, corrected to deduct any wood which has come from forest and grassland conversion (CO_2 already accounted for) is also a key input for calculating net CO_2 emissions or removals due to changes in forest and other woody biomass stocks.

5.2 Changes in forest and other woody biomass stocks

Introduction

This submodule deals with the emissions or removals of carbon (and carbon dioxide) due to changes in forest and other woody biomass stocks affected by human activity.

Data sources

FAO Yearbooks of Forest Products (annual)

There are also a number of international data bases with country-specific statistics, as well as studies of individual countries. These include:

Forest Resources Assessment 1990: Tropical Countries (FAO, 1993).

The Forest Resources of the Temperate Zones (ECE/FAO, Geneva, 1992).

For a fuller bibliography, see *The IPCC Greenhouse Gas Inventory Reference Manual.*

Methodology

CATEGORIES OF WOODY BIOMASS

Village, farm or urban trees and other afforestation programmes are included to allow users to account for biomass in trees outside normal forests. These may be important for fuelwood accounting in some countries. Users must provide all data for these categories.

To calculate the net uptake of CO_2, the annual increment of biomass in plantations, forests which are logged or otherwise harvested, the growth of trees in villages, farms and urban areas and any other significant stocks of woody biomass, is estimated.

Wood harvested for fuelwood, commercial timber and other uses is also estimated. There are two approaches you can use when estimating wood removals:

- commercial harvest statistics
- traditional fuelwood consumption estimates from the *CO_2 from Energy* submodule

For some countries commercial statistics will give only a partial account of wood removals and using both sources of statistics may provide the most accurate picture.

The net carbon uptake due to these sources is then calculated. If the figure is positive then this counts as a removal of CO_2, and if the figure is negative, it counts as an emission. Finally, the net carbon uptake/emission is expressed as CO_2.

Completing the Worksheet

STEP 1 ESTIMATING TOTAL CARBON CONTENT IN ANNUAL GROWTH OF LOGGED AND PLANTED FORESTS

Use WORKSHEET 5-1 CHANGES IN FOREST AND OTHER WOODY BIOMASS STOCKS at the end of this section to record inventory data.

1 For each type of biomass stock, enter the Area of Forest/Biomass stocks in kilohectares (kha) in column A.

2 For dispersed trees (e.g., urban, village and farm trees), enter the number of trees (in 1000s of trees) in column A.

3 For each type of forest, enter the Annual Growth Rate (in tonnes of dry matter per hectare) in column B.

The default statistics in Table 5-1 or 5-6 can be used if national data are not available. Using defaults would result in highly uncertain national estimates.

TABLE 5-1
AVERAGE ANNUAL ACCUMULATION OF DRY MATTER AS BIOMASS IN PLANTATIONS

Forest Types		Annual Increment in Biomass (tonnes dm/ha/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

Note: These are average accumulation rates over expected plantation lifetimes; actual rates will depend upon the age of the plantation.

The data for the temperate species are based upon 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 country can be derived from data in ECE/FAO (1985), assuming that country averages of net annual increment for managed and unmanaged lands are reasonable approximations for plantations.

4 For other non-forest trees, enter the Annual Growth Rate in kilotonnes of dry matter per thousand trees in column B, i.e., take average growth rate per tree and multiply by 1,000.

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary.

USING COMMERCIAL HARVEST STATISTICS

Commercial harvest statistics are often provided for the commercial portion of the biomass only, in cubic metres (m^3) of roundwood. In this case the harvested amounts must be adjusted in two ways to reflect the values needed for the emissions/removals calculations. The volume of biomass expressed as m^3 must be converted to mass of dry matter expressed as tonnes (t dm).

- The default conversion ratio is 0.5 t dm/m^3.

In addition, an expansion ratio can be applied to account for the non-commercial biomass (limbs, small trees etc.) harvested with the commercial roundwood and left to decay. The following default ratios can be used:

- Undisturbed forests 1.75
  Logged forests 1.90
  Unproductive forests 2.00

If the forest type from which commercial roundwood has been harvested is known, the appropriate ratio can be applied. The value for logged forests could be used as a general default. More detailed formulae for deriving expansion ratio as a function of pre-harvest biomass density are discussed in the *Reference Manual*.

If both conversion and expansion are needed, they can be combined by using ratios which are the product of the two:

Forest type	*t dm total biomass/m^3 commercial roundwood*
Undisturbed forests	*0.88*
Logged forests	*0.95*
Unproductive forests	*1.0*

Some harvest statistics are provided on a total biomass basis (expansion ratios already applied) or may be provided in mass of dry matter rather than volume. It is important that users determine carefully the nature of the values in their sources of commercial harvest data, then apply the appropriate conversions or expansions to get total biomass harvested. This can be:

a volume to mass conversion alone

b expansion from commercial to total mass of dry matter

c a combination of both (*a* and *b*)

5 For each type of forest/grassland, multiply the Area of Forest/Biomass Stocks by the Annual Growth Rate to give the Annual Biomass Increment in kilotonnes of dry matter. Enter the result in column C.

6 For non-forest trees, multiply the Number of Trees by the Annual Growth Rate to give the Annual Biomass Increment in kilotonnes of dry matter. Enter the result in column C.

7 For each type of biomass stock, enter the Carbon Fraction of Dry Matter.

The default value is 0.45 for all biomass, if specific values are not available.

8 Multiply the Annual Biomass Increment by the Carbon Fraction of Dry Matter to give the Total Carbon Uptake Increment. Enter the result in column E.

9 Add the figures in column E and enter the total in the Total box at the bottom of the column.

STEP 2 ESTIMATE THE AMOUNT OF BIOMASS HARVESTED

1 Enter the amount of the Commercial Harvest in thousands of cubic metres in column F.

These values should be taken from local sources. FAO published values can be used as defaults. See the margin box *Using Commercial Harvest Statistics*.

2 Enter the Biomass Conversion/Expansion Ratio in tonnes of dry matter per cubic metre (t dm/m^3) in column G if necessary.

3 Multiply the Commercial Harvest by the Biomass Conversion/Expansion Ratio (if necessary) to give the Total Biomass Removed in Commercial Harvest in kilotonnes of dry matter. Enter the result in column H.

4 Enter Total Traditional Fuelwood Consumed (including wood for charcoal production) from survey-based accounting (if applicable) in column I. This accounting should have been done in Biomass Fuels in Module 1. See Worksheet 1-2: Optional Fuelwood Consumption Accounting.

5 Enter the quantity of Total Other Wood Use in kilotonnes dm in column J.

If any wood is removed but is not accounted for in harvest statistics for commercial harvest or fuelwood consumption accounts, it can be entered here.

6 Add the Total Traditional Fuelwood Consumed (column I) to the Total Biomass Removed in Commercial Harvest (column H) and Total Other Wood Use (column J) to give Total Biomass Consumption. Enter the result in column K. Sum this column and enter the result in the Totals box at the foot of the column.

7 Enter Wood Removed From Forest Clearing (figure from column M, Worksheet 5-2, sheet 3, Quantity of Biomass Burned Off Site) at the bottom of column L.

8 Subtract Wood Removed From Forest Clearing from Total Biomass Consumption to give Total Biomass Consumption From Stocks in kilotonnes of dry matter. Enter the result in the box at the bottom of column M.

STEP 3 CONVERT WOOD HARVESTED TO CARBON REMOVED

1 Enter the Carbon Fraction in column N (the general default value for live biomass is 0.45).

2 Multiply Total Biomass Consumption From Stocks (column M) by Carbon Fraction (column N) to give Annual Carbon Release (in kilotonnes of carbon). Enter the result in column O.

STEP 4 ESTIMATE THE NET ANNUAL AMOUNT OF CARBON UPTAKE OR RELEASE

1 Subtract Annual Carbon Release (column O) from Total Carbon Increment (column E) to give Net Annual Carbon Uptake or Release. Enter the result in column P.

2 Multiply the Net Annual Carbon Uptake or Release (column P) by 44/12 to give the Annual CO_2 Removal (if a positive value) or Emission (if a negative value). Enter the result in column Q.

3 For summary reporting purposes and for consistency with other emission/removal categories, it is necessary to reverse the sign of these results, to express emissions as a positive value and removals as negative.

5.3 CO_2 Emissions from Forest and Grassland Conversion

Introduction

Forest and grassland conversion to permanent cropland or pasture, primarily an activity of the tropics. Tropical Forest clearing is usually accomplished by cutting undergrowth and felling trees followed by burning biomass on-site or as fuelwood. By this process some of the biomass is burned while some remains on the ground where it decays slowly (usually over a period of ten years in the tropics). Of the burned material, a small fraction (5-10 per cent) is converted to charcoal which resists decay for 100 years or more, and the remainder is released instantaneously into the atmosphere as CO_2.

Carbon is also lost from the soils after conversion, particularly when the land is cultivated. This can occur over 25 years or more. Conversion of grasslands into cultivated lands also results in CO_2 emissions, mainly from soils.

Data sources

To carry out the inventory task in this section you need the following forest/grassland area statistics.

Forest/grassland areas converted to cropland and pasture, by type over three time periods:

- the inventory year
- the past ten years
- the past 25 years

Satellite images, aerial photography and land-based surveys are all possible sources of data.

There are also a number of international data bases with country-specific statistics, as well as studies of individual countries. These include:

Forest Resources Assessment 1990: Tropical Countries (FAO, 1993).

The Forest Resources of the Temperate Zones, (ECE/FAO, Geneva, 1992).

For a fuller bibliography, see *The IPCC Greenhouse Gas Inventory Reference Manual.*

Methodology

Three sets of calculations are used to produce estimates of CO_2 emissions due to forest/grassland conversion:

- Carbon emitted by burning aboveground biomass (*immediate emissions, occurring in the year of conversion*)

- Carbon released by decay of aboveground biomass (*delayed* emissions, occurring over a ten-year period)
- Carbon released from soil (*delayed* emissions, occurring over a 25-year period)

The totals are added together to arrive at total for carbon released. Total carbon released is then converted to CO_2 emissions.

Completing the Worksheet

STEP 1 ESTIMATING BIOMASS CLEARED

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary.

Use WORKSHEET 5-2 FOREST AND GRASSLAND CONVERSION, at the end of this section to record inventory data. You should do this for each forest/grassland type:

1 Enter the figures for Area Converted Annually in kilohectares in column A.

See the *Reference* Manual, Chapter 5, Technical Appendix for a discussion of international sources of data.

2 Enter the figures for dry matter *before* conversion in tonnes of dry matter per hectare (t dm/ha) in column B. Default values are shown in Tables 5-2 and 5-3.

TABLE 5-2
DRY MATTER IN ABOVEGROUND BIOMASS IN TROPICAL FORESTS
(t dm / ha)

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

Source: See *Greenhouse Gas Inventory Reference Manual*

TABLE 5-3
DRY MATTER IN ABOVEGROUND BIOMASS IN TEMPERATE AND BOREAL FORESTS
(t dm / ha)

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

Sources: See *Greenhouse Gas Inventory Reference Manual*

3 Enter the figures *after* conversion in tonnes of dry matter per hectare (t dm/ha) in column C.

This figure includes any biomass not fully cleared (default value = 0) plus regrowth in agricultural use (the default is 10 tonnes dry matter per hectare).

4 Subtract the figures in column C from the figures in column B to produce the figure for Net Change in Biomass Density in tonnes of dry matter per hectare and enter the result in column D.

5 Multiply the Area Converted Annually (in kilohectares) by the Net Change in Biomass Density (in tonnes per hectare) to calculate the Annual Loss of Biomass for each forest/grassland type in kilotonnes of dry matter (kt dm). Enter the results in column E.

FRACTIONS

Various fractions are used in calculating the emissions from forest/grassland conversion.

- Fraction biomass burned on-site and off-site
- Fraction left to decay

  This is the portion of the biomass which is simply left to decay and so releases gases at a slower rate.
- Fraction which oxidises

  This is the fraction of burned biomass which actually oxidises instead of turning to charcoal.

STEP 2 ESTIMATING CARBON RELEASED BY BURNING ABOVEGROUND BIOMASS ON-SITE

1 Enter figures for the fraction of biomass burned on site by forest/grassland type in column F.

2 Multiply the Annual Loss of Biomass (in kilotonnes) by the Fraction of Biomass Burned On Site to calculate the Quantity of Biomass Burned On Site (in kilotonnes of dry matter) for each forest/grassland type. Enter the result in column G.

3 Enter the Fraction of Biomass Oxidised On Site in column H (default fraction 0.9).

4 Multiply Quantity of Biomass Burned On Site (in kilotonnes of dry matter) by the Fraction of Biomass Oxidised On Site to calculate the Quantity of Biomass Oxidised On Site (in kilotonnes of dry matter). Enter the figures in column I.

5 Enter the Carbon Fraction of the Aboveground Biomass (burned on site) in column J (default fraction 0.45).

6 Multiply the Quantity of Biomass Oxidised On Site (in kilotonnes of dry matter) by the Carbon Fraction of the Aboveground Biomass to calculate the Quantity of Carbon Released (in kilotonnes carbon). Enter the results in column K.

7 Total the figures in column K and enter the figure in the Subtotal box at the bottom of column on the Worksheet.

This subtotal will be used later to estimate emissions of other gases from burning on-site. (Worksheet 5-3)

STEP 3 ESTIMATING CARBON RELEASED BY BURNING ABOVEGROUND BIOMASS OFF-SITE

1 Enter the Fraction of Biomass Burned Off Site in column L.

2 Multiply the Annual Loss of Biomass (in kilotonnes of dry matter) from column E by the Fraction of Biomass Burned Off Site to calculate the

Quantity of Biomass Burned Off Site (in kilotonnes of dry matter) for each forest/grassland type. Enter the result in column M.

3 Total the figures in column M and enter the figure in the Subtotal box at the bottom of column on the Worksheet.

This subtotal will be used In Worksheet 5-1 *Changes in Forest and Other Woody Biomass Stocks.*

4 Enter the Fraction of Biomass Oxidised Off Site for each forest/grassland type in column N (default value 0.9).

5 Multiply Quantity of Biomass Burned Off Site (in kilotonnes of dry matter) by the Fraction Oxidised to calculate the Quantity of Biomass Oxidised Off Site (in kilotonnes of dry matter). Enter the figures in column O.

6 Enter the Carbon Fraction of the Aboveground Biomass (burned off site) in column P (default fraction 0.45).

7 Multiply the Quantity of Biomass Oxidised Off Site (in kilotonnes of dry matter) by the Carbon Fraction of the Aboveground Biomass to calculate the Quantity of Carbon Released (in kilotonnes). Enter the results in column Q.

8 Total the figures in column Q and enter the figure in the Subtotal box at the bottom of column on the Worksheet

STEP 4 ESTIMATING TOTAL CARBON RELEASED BY BURNING ABOVEGROUND BIOMASS ON- AND OFF-SITE

1 Add the subtotal for the Quantity of Carbon released (from biomass burned on site) in column K to the subtotal for the Quantity of Carbon released (from biomass burned off site) in column Q. The result is the Total Carbon Released (from on and off site burning). Enter the result in the subtotal box at the bottom of column R.

2 Multiply the Total Carbon Released by 44/12 to calculate the Total CO_2 Released (from on and off site burning). Enter the result in the subtotal box at the bottom of column S.

STEP 5 ESTIMATING CO_2 RELEASED BY DECAY OF ABOVEGROUND BIOMASS

1 Enter figures for Average Area Converted (average over ten years) for each forest/grassland type in column A.

Some information on international data sources is provided in the *Reference Manual* Chapter 5, *Technical Appendix*.

2 Enter the average biomass density in tonnes of dry matter per hectare (t dm/ha) *before* conversion in column B. Default values are provided in Tables 5-2 and 5-3.

3 Enter the average biomass density in tonnes of dry matter per hectare (t dm/ha) *after* conversion in column C.

ESTIMATING FRACTION LEFT TO DECAY

In the Amazon, *Fraction Left to Decay* is typically about 0.5 but this varies greatly by region. Country experts must provide this value.

There is a relationship between the fraction left to decay here and the fraction burned on and off site. For a given year the fraction burned, the fraction left to decay (and possibly a fraction harvested as commercial timber or other non-fuel use) should sum to 1.0, accounting for all biomass cleared. Because the burning and decay portions are averaged over different time periods in the methodology, the relationship need not be precise. However, assumptions made for these different fractions should be consistent.

This figure includes any biomass not fully cleared (default value = 0) and biomass regrowth in agricultural use (the default is 10 tonnes dry matter per hectare).

4 Subtract the value in column C from the value in column B to produce Net Change in Biomass Density in tonnes of dry matter per hectare. Enter the results in column D.

5 Multiply the Average Area Converted (10 Year Average) in kilohectares (column A) by the Net Change in Biomass Density in tonnes dry matter per hectare (column D) to calculate the Average Annual Loss of Biomass (aboveground) for each forest/grassland type in kilotonnes of dry matter (kt dm). Enter the results in column E.

6 Enter Fraction Left to Decay (10-Year average) in column F.

7 Multiply the Average Annual Loss of Biomass for each forest/grassland type by the Fraction Left to Decay to calculate the Quantity of Biomass Left to Decay. Enter the result in column G.

8 Enter the Carbon Fraction in Aboveground Biomass in column H (default fraction 0.45).

9 Multiply the Quantity of Biomass Left to Decay (column G) by the Carbon Fraction (column H) to calculate Carbon Released from Decay of Aboveground Biomass. Enter the figures in column I.

10 Add the figures in column I and enter the total in the subtotal box at the bottom of the column.

STEP 6 ESTIMATING CARBON RELEASED BY SOIL

CAUTION

There is no scientific consensus on whether clearing leads to significant soil carbon loss in **tropical** forests. This calculation is optional for tropical forests.

1 Enter the Average Annual Forest/Grassland Converted over the last 25 years in kilohectares in column A.

There are no default data for this figure.

2 Enter the Soil Carbon Content Before Conversion by forest or grassland type in column B. See Table 5-4 for forest soil defaults.

Default values for grasslands are 60 tonnes/ha for tropical and 70 tonnes/ha for temperate zones.

TABLE 5-4
CARBON IN FOREST SOILS
(tonnes C / ha)

Tropical Forests	*Moist*	*Seasonal*	*Dry*
America	115	100	60
Africa	115	100	60
Asia	115	100	60
Temperate Forests	*Evergreen*	*Deciduous*	
Primary	134	134	
Secondary	120	120	
Boreal Forests			
Primary	206		
Secondary	185		
See the *Greenhouse Gas Inventory Reference Manual* for sources.			

3 Multiply Average Annual Forest/Grassland Converted (column A) by the Carbon Content of Soil Before Conversion (column B) to calculate the Total Annual Potential Soil Carbon Losses. Enter the result in column C.

4 Enter Fraction of Carbon Released over 25 years in column D (default fraction 0.5).

5 Multiply Total Annual Potential Soil Carbon Losses by the Fraction of Carbon Released to give the Carbon Release from Soil. Enter the result in column E.

6 Add the totals for each forest/grassland type and enter the total in the subtotal box at the bottom of column E.

STEP 7 ESTIMATING TOTAL CO_2 EMISSIONS FROM FOREST AND GRASSLAND CONVERSION

1 Enter the total for Immediate Release from Burning (contained in the subtotal box of column R in Worksheet 5-2, Sheet 3) in column A.

2 Enter the total for Delayed Emissions from Decay (contained in the subtotal box of column I in Worksheet 5-2, Sheet 4) in column B.

3 Enter the total for Long-Term Emissions from Soil conversion (contained in the subtotal box of column E in Worksheet 5-2, Sheet 5) in column C.

4 Add the figures in columns A, B and C to calculate the Total Annual Carbon Release (in the inventory year from clearing over a 25 year period). Enter the result in column D.

5 Multiply the Total Annual Carbon Release by 44/12 to convert it into the Total Annual CO_2 Release (in Gg). Enter the result in column E.

5.4 On-site burning of forests: Emissions of non-CO_2 trace gases

Introduction

For on-site burning of forests, the method of calculation is very similar to that for non-CO_2 trace gases from burning of traditional biomass for energy. All burning of biomass (e.g. fuelwood, dung) for energy and of savannas and agricultural wastes is a significant source of CH_4, N_2O, CO and NO_x. Net CO_2 emissions from forest/grassland conversion were calculated in Section 5.3 above. Emissions of non-CO_2 trace gases from on-site burning of forests are calculated here.

Methodology

The method relies on estimation of the gross carbon flux based on work done in section 5.3 of this *Workbook*.

CH_4 and CO are estimated as ratios to carbon fluxes emitted during burning. Total nitrogen content is estimated based on the nitrogen-carbon ratio. N_2O and NO_x are estimated as ratios to total nitrogen.

Completing the Worksheet

Use WORKSHEET 5-3 ON-SITE BURNING OF FORESTS to enter data for this submodule.

STEP 1 ESTIMATING NITROGEN RELEASED

1 Enter the estimate of Quantity of Carbon Released from on-site burning of forests (in kilotonnes carbon) in column A.

Take this figure from the Total in column K of Worksheet 5-2, Sheet 2, *Forest/Grassland Conversion*.

2 Enter the Nitrogen-Carbon Ratio of Biomass Burned in column B.

The general default value is 0.01.

3 Multiply Quantity of Carbon Released by the Nitrogen-Carbon Ratio to give the Total Nitrogen Released. Enter the total in kilotonnes of nitrogen in column C.

STEP 2 ESTIMATING NON-CO_2 TRACE GAS EMISSIONS

1 Enter Trace Gas Emissions Ratios in column D.

Refer to Table 5-5 for non-CO_2 trace gas emissions ratios.

TABLE 5-5 EMISSION RATIOS FOR OPEN BURNING OF FORESTS	
Compound	*Ratio*
CH_4	0.012 (0.009 - 0.015)
CO	0.06 (0.04 - 0.08)
N_2O	0.007 (0.005 - 0.009)
NO_x	0.121 (0.094 - 0.148)

Note: Ratios for carbon compounds are mass of carbon released as CH_4 or CO (in units of C) relative to mass of total carbon released from burning (in units of C). Those for nitrogen compounds are expressed as the ratios of nitrogen released as N_2O and NO_x relative to the nitrogen content of the fuel (in units of N).

See the *Greenhouse Gas Inventory Reference Manual* for sources.

2 Multiply Quantity of Carbon Released (column A) by the emissions ratio for CH_4 to give the Amount of CH_4 released. Enter the amount in kilotonnes of C in column E.

3 Multiply Quantity of Carbon Released (column A) by the emissions ratio for CO to give the Amount of CO released. Enter the amount in kilotonnes of C in column E.

4 Multiply the Total Nitrogen Released (column C) by the emissions ratio for N_2O to give the Amount of N_2O Released. Enter the amount in kilotonnes of N in column E.

5 Multiply the Total Nitrogen Released (column C) by the emissions ratio for NO_x to give the Amount of NO_x Released. Enter the amount in kilotonnes of N in column E.

6 Multiply the figures in column E by the conversion ratios[1] in column F to give total for the release of CH_4, CO, N_2O and NO_x. Enter the results in gigagrams, which is the same as kilotonnes, in column G.

[1] The molecular weight ratios given above for the emitted gases are with respect to the weight of nitrogen and carbon in the molecule. Thus for N_2O the ratio is 44/28 and for NO_X it is 46/14. NO_2 has been used as the reference molecule for NO_X.

5.5 Abandonment of managed lands

Introduction

This submodule deals with removals resulting from the abandonment of *managed* lands. Managed lands include:

- Cultivated lands (arable land used for the cultivation of crops)
- Pasture (land used for grazing animals)

Carbon accumulation on abandoned lands is sensitive to the type of natural ecosystem (forest type or grasslands) which is regrowing. Therefore abandoned lands regrowing should be entered by type. For grasslands the default assumption is that net accumulation aboveground is zero. Only soil carbon is calculated in that case.

Because regrowth rates become slower after a time, the periods considered are

- Land abandoned during the 20 years prior to the inventory year (i.e. 1990)
- Land abandoned between 20 and 100 years ago (i.e. before 1970 and after 1870)

When managed lands are abandoned, carbon may or may not reaccumulate on the land. Abandoned areas are therefore split into those which reaccumulate carbon and those which do not regrow or which continue to degrade.

Only natural lands which are regrowing towards a natural state should be included. Lands which do not regrow or degrade should be ignored in this calculation.

As with forest and grassland conversion, there is controversy over the effect of forest regrowth on soil carbon in tropical regions. These calculations are all optional but you should ensure that you treat soil carbon from forest and grassland conversion and abandoned lands consistently.

Methodology

Four sets of calculations are used to produce estimates of CO_2 removals from biomass regrowth and soils. They relate to the quantity of land abandoned and the length of time for which it has been abandoned:

- Annual carbon uptake in aboveground biomass (land abandoned in the last twenty years)
- Annual carbon uptake in soils (land abandoned in the last twenty years)
- Annual carbon uptake in aboveground biomass (land abandoned for between twenty and a hundred years, if applicable)
- Annual carbon uptake in soils (land abandoned for between twenty and a hundred years, if applicable)

These are then totalled and the carbon uptake is converted into CO_2 removals.

Completing the Worksheet

Use WORKSHEET 5-4 ABANDONMENT OF MANAGED LANDS at the end of this section to record inventory data.

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary.

STEP 1 CALCULATE ANNUAL CARBON UPTAKE IN ABOVEGROUND BIOMASS (LAND ABANDONED IN THE LAST TWENTY YEARS)

1 Enter the Total Area Abandoned and Regrowing for the last twenty years (in kilohectares) in column A.

There are no default data for these figures.

2 Enter the Annual Rate of Aboveground Biomass Growth (in tonnes dry matter per hectare) in column B. See Table 5-6 for defaults.

TABLE 5-6
ANNUAL AVERAGE ABOVEGROUND BIOMASS UPTAKE BY NATURAL REGENERATION
tonnes dm/ha

Tropical Regions		Forest Types					
		Moist Forests		Seasonal Forests		Dry Forests	
		0-20 Years	20-100 Years	0-20 Years	20-100 Years	0-20 Years	20-100 Years
	America	8.0	0.9	5.0	0.5	4.0	0.25
	Africa	11	1.0	7.0	0.7	4.0	0.25
	Asia	11	1.0	7.0	0.7	4.0	0.25
		0-20 Years		20-100 Years			
Temperate Forests							
	Evergreen	3.0		3.0			
	Deciduous	2.0		2.0			
Boreal Forests		1.0		1.0			

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

ALL OF THESE REGIONAL AVERAGE GROWTH RATES SHOULD BE CONSIDERED INDICATIVE ONLY. IF FORESTS ARE A SIGNIFICANT PART OF A COUNTRY'S TOTAL GHG INVENTORY, LOCALLY AVAILABLE DATA OR EXPERT JUDGEMENT SHOULD BE SOUGHT TO DEVELOP VALUES REFLECTING CONDITIONS AND PRACTICES.

See the *Greenhouse Gas Inventory Reference Manual* for sources.

3 Multiply the Total Area Abandoned and Regrowing (column A) by the Annual Rate of Aboveground Biomass Growth (column B) to give the Annual Aboveground Biomass Growth (in kt dm). Enter the result in column C.

4 Enter the Carbon Fraction of Aboveground Biomass in column D (default fraction 0.45).

5 Multiply the Annual Aboveground Biomass Growth (column C) by the Carbon Fraction of Aboveground Biomass (column D) to give the Annual Carbon Uptake in Aboveground Biomass. Enter the result in column E.

6 Add the figures in column E and enter the total in the subtotal box at the bottom of the column.

STEP 2 CALCULATE ANNUAL CARBON UPTAKE IN SOILS (LAND ABANDONED IN LAST TWENTY YEARS)

1 Enter the Annual Rate of Uptake of Carbon in Soils (in tonnes of carbon per hectare) in column F.

Default values for soil carbon accumulation in temperate and boreal forests are provided in Table 5-7. No values are available for tropical systems or grasslands.

TABLE 5-7
ANNUAL SOIL CARBON ACCUMULATION IN TEMPERATE AND BOREAL FORESTS
(tonnes C/ha/yr)

Temperate		Boreal
Evergreen	Deciduous	
1.3	1.3	2.0

Source: IPCC estimates; see *Reference Manual.*

2 Multiply the Total Area Abandoned and Regrowing (column A) by the Annual Rate of Uptake of Carbon in Soils (column F) to give the Total Annual Carbon Uptake in Soils (in kilotonnes of carbon). Enter the results in column G.

3 Add the figures in column G and enter the total in the subtotal box at the bottom of the column.

STEP 3 CALCULATE ANNUAL CARBON UPTAKE IN ABOVEGROUND BIOMASS (LAND ABANDONED FOR MORE THAN TWENTY YEARS)

1 Enter the Total Area Abandoned for more than twenty years (in kilohectares) in column H.

2 Enter the Annual Rate of Aboveground Biomass Growth (in tonnes of dry matter per hectare) in column I.

Table 5-6 provides default values.

3 Multiply the Total Area Abandoned (column H) by the Annual Rate of Aboveground Biomass Growth (column I) to give the Annual Aboveground Biomass Growth (in kt dm). Enter the result in column J.

4 Enter the Carbon Fraction of Aboveground Biomass in column K (default fraction 0.45).

5 Multiply the Annual Aboveground Biomass Growth (column J) by the Carbon Fraction of Aboveground Biomass (column K) to give the Annual Carbon Uptake in Aboveground Biomass. Enter the result in column L.

6 Add the figures in column L and enter the total in the subtotal box at the bottom of the column.

STEP 4 CALCULATE ANNUAL CARBON UPTAKE IN SOILS (LAND ABANDONED FOR MORE THAN TWENTY YEARS)

1 Enter the Annual Rate of Uptake of Carbon in Soils (in tonnes carbon/hectare) in column M.

Default values are 0.5 times the values in Table 5-7.

2 Multiply the Total Area Abandoned (column H) by the Annual Rate of Uptake of Carbon in Soils (column M) to give the Total Annual Carbon Uptake in Soils (in kilotonnes of carbon). Enter the results in column N.

3 Add the figures in column N and enter the total in the subtotal box at the bottom of the column.

STEP 5 CALCULATE TOTAL CO_2 REMOVALS FROM ABANDONED LANDS

1 Add the subtotals from columns E, G, L and N and enter the Total Carbon Uptake from Abandoned Lands in column O.

2 Multiply the Total Carbon Uptake from Abandoned Lands by 44/12 to give the Total Carbon Dioxide Uptake from the abandonment of managed lands in Gg. Enter the result in column P.

3 For summary reporting purposes and for consistency with other emission/removal categories, it is necessary to reverse the sign of these results, so that the removal of CO_2 by abandoned lands is expressed as a negative (i.e., negative emissions) value.

MODULE			**LAND USE CHANGE AND FORESTRY**				
SUBMODULE			**CHANGES IN FOREST AND OTHER WOODY BIOMASS STOCKS**				
WORKSHEET			**5-1**				
SHEET			**1 OF 3**				
			STEP 1				
			A Area of Forest/Biomass Stocks (kha)	B Annual Growth Rate (t dm/ha)	C Annual Biomass Increment (kt dm)	D Carbon Fraction of Dry Matter	E Total Carbon Uptake Increment (kt C)
					C=(AxB)		E=(CxD)
Tropical	Plantations	Acacia spp.					
		Eucalyptus spp.					
		Tectona grandis					
		Pinus spp					
		Pinus caribaea					
		Mixed Hardwoods					
		Mixed Fast-Growing Hardwoods					
		Mixed Softwoods					
	Other Forests	Moist					
		Seasonal					
		Dry					
	Other (specify)						
Temperate	Plantations	Douglas fir					
		Loblolly pine					
	Commercial	Evergreen					
		Deciduous					
	Other						
Boreal							
Non-Forest Trees (specify type)			A Number of Trees (1000s of trees)	B Annual Growth Rate (kt dm/1000 trees)			
						Total	

MODULE	LAND USE CHANGE AND FORESTRY
SUBMODULE	CHANGES IN FOREST AND OTHER WOODY BIOMASS STOCKS
WORKSHEET	5-1
SHEET	2 OF 3

	STEP 2							
	F	G	H	I	J	K	L	M
Harvest Categories (specify)	Commercial Harvest (if applicable) (1000 m^3 roundwood)	Biomass Conversion/ Expansion Ratio (if applicable) (t dm/m^3)	Total Biomass Removed in Commercial Harvest (kt dm)	Total Traditional Fuelwood Consumed (kt dm)	Total Other Wood Use (kt dm)	Total Biomass Con-sumption (kt dm)	Wood Removed From Forest Clearing (kt dm)	Total Biomass Consump-tion From Stocks (kt dm)
			H=(FxG)	(From column H, Worksheet 1-2)		K=(H+I+J)	(From column M, Worksheet 5-2, sheet 3)	M=K-L
Totals								

MODULE	LAND USE AND FORESTRY
SUBMODULE	CHANGES IN FOREST AND OTHER WOODY BIOMASS STOCKS
WORKSHEET	5-1
SHEET	3 OF 3

STEP 3

N	O	P	Q
Carbon Fraction	Annual Carbon Release (kt C)	Net Annual Carbon Uptake (+) or Release (-) (kt C)	Convert to CO_2 Annual Emission (-) or Removal (+) (Gg CO_2)
	O=(MxN)	P=(E-O)	Q=(Px[44/12])

MODULE	LAND USE CHANGE AND FORESTRY
SUBMODULE	FOREST AND GRASSLAND CONVERSION
WORKSHEET	5-2
SHEET	1 OF 6

STEP 1

Land types			A Area Converted Annually (kha)	B Biomass Before Conversion (t dm/ha)	C Biomass After Conversion (t dm/ha)	D Net Change in Biomass Density (t dm/ha)	E Annual Loss of Biomass (kt dm)
						D=(B-C)	E=(AxD)
Tropical	Moist Forests	Primary					
		Secondary					
	Seasonal Forests	Primary					
		Secondary					
	Dry Forests or Woody Savannas	Primary					
		Degraded					
Temperate	Evergreen:	Primary					
		Secondary					
	Deciduous	Primary					
		Secondary					
Boreal	Primary						
	Secondary						
Grassland							
Other							

MODULE	**LAND USE CHANGE AND FORESTRY**
SUBMODULE	**FOREST AND GRASSLAND CONVERSION**
WORKSHEET	**5-2**
SHEET	**2 OF 6**

STEP 2

Land types			F Fraction of Biomass Burned On Site	G Quantity of Biomass Burned On Site (kt dm)	H Fraction of Biomass Oxidised On Site	I Quantity of Biomass Oxidised On Site (kt dm)	J Carbon Fraction of Above-ground Biomass (burned on site)	K Quantity of Carbon Released (from biomass burned) (kt C)
				G=(ExF)		I=(GxH)		K=(IxJ)
Tropical	Moist	Primary						
	Forests	Secondary						
	Seasonal	Primary						
	Forests	Secondary						
	Dry Forests	Primary						
	or Woody Savannas	Degraded						
Temperate	Evergreen:	Primary						
		Secondary						
	Deciduous	Primary						
		Secondary						
Boreal	Primary							
	Secondary							
Grassland								
Other								
							Subtotal	

MODULE	**LAND USE CHANGE AND FORESTRY**
SUBMODULE	**FOREST AND GRASSLAND CONVERSION**
WORKSHEET	**5-2**
SHEET	**3 OF 6**

			STEP 3						STEP 4	
Land types			L	M	N	O	P	Q	R	S
			Fraction of Biomass Burned Off Site	Quantity of Biomass Burned Off Site (kt dm)	Fraction of Biomass Oxidised Off Site	Quantity of Biomass Oxidised Off Site (kt dm)	Carbon Fraction of Above-ground Biomass (burned off site)	Quantity of Carbon Released (from biomass burned off site (kt C)	Total Carbon Released (from on & off site burning) (kt C)	Total CO_2 released (from on & off site burning) (kt CO_2)
				M=(ExL)		O=(MxN)		Q=(OxP)	R=(K+Q)	S= Rx[44/12]
Tropical	Moist Forests	Primary								
		Secondary								
	Seasonal Forests	Primary								
		Secondary								
	Dry Forests or Woody Savannas	Primary								
		Degraded								
Temperate	Evergreen:	Primary								
		Secondary								
	Deciduous	Primary								
		Secondary								
Boreal	Primary									
	Secondary									
Grassland										
Other										
			Subtotal				**Subtotal**			

MODULE	**LAND USE CHANGE AND FORESTRY**
SUBMODULE	**FOREST AND GRASSLAND CONVERSION**
WORKSHEET	**5-2**
SHEET	**4 OF 6**

			STEP 5								
Land types			A	B	C	D	E	F	G	H	I
			Average Area Converted (10 Year Average)	Biomass Before Conversion	Biomass After Conversion	Net Change in Biomass Density	Average Annual Loss of Biomass	Fraction Left to Decay	Quantity of Biomass Left to Decay	Carbon Fraction in Above-ground Biomass	C Released from Decay of Above-ground Biomass
			(kha)	(t dm/ha)	(t dm/ha)	(t dm/ha)	(kt dm)		(kt dm)		(kt C)
						D=(B-C)	E=(AxD)		G=(ExF)		I=(GxH)
Tropical	Moist Forests	Primary									
		Secondary									
	Seasonal Forests	Primary									
		Secondary									
	Dry Forests or Woody Savannas	Primary									
		Degraded									
Temperate	Evergreen:	Primary									
		Secondary									
	Deciduous	Primary									
		Secondary									
Boreal	Primary										
	Secondary										
Grassland											
Other											
										Subtotal	

MODULE	LAND USE CHANGE AND FORESTRY
SUBMODULE	FOREST AND GRASSLAND CONVERSION
WORKSHEET	5-2
SHEET	5 OF 6

				STEP 6				
Land Type				A Average Annual Forest/ Grassland Converted (25 year average) (kha)	B Carbon Content of Soil Before Conversion (t/ha)	C Total Annual Potential Soil Carbon Losses (kt C)	D Fraction of Carbon Released over 25 years	E Carbon Release from Soil (kt C)
						C=AxB		E=(CxD)
Tropical	Moist Forests	Primary						
		Secondary						
	Seasonal Forests	Primary						
		Secondary						
	Dry Forests or Woody Savannas	Primary						
		Degraded						
Temperate	Evergreen	Primary						
		Secondary						
	Deciduous	Primary						
		Secondary						
Boreal	Primary							
	Secondary							
Grassland								
Other								
							Subtotal	

MODULE	**LAND USE CHANGE AND FORESTRY**
SUBMODULE	**FOREST AND GRASSLAND CONVERSION**
WORKSHEET	**5-2**
SHEET	**6 OF 6**

STEP 7				
A Immediate Release From Burning (kt C)	B Delayed Emissions From Decay (kt C) (10-year average)	C Long Term Emissions From Soil (kt C) (25-year average)	D Total Annual Carbon Release (kt C)	E Total Annual CO_2 Release (Gg CO_2)
			D=(A+B+C)	E=(Dx[44/12])

MODULE	LAND USE CHANGE AND FORESTRY
SUBMODULE	ON-SITE BURNING OF FORESTS
WORKSHEET	5-3
SHEET	1 OF 1

STEP 1			STEP 2				
A	B	C		D	E	F	G
Quantity of Carbon Released	Nitrogen-Carbon Ratio	Total Nitrogen Released		Trace Gas Emissions Ratios	Trace Gas Emissions	Conversion Ratio	Trace Gas Emissions from Burning of Cleared Forests
(kt C)		(kt N)			(kt C)		(Gg CH_4, CO)
(From column K,sheet 2, of Worksheet 5-2)		C=(AxB)			E=(AxD)		G=(ExF)
			CH_4			16/12	
			CO			28/12	
					kt N		Gg N_2O, NO_x
					E=(CxD)		G=(ExF)
			N_2O			44/28	
			NO_x			46/14	

		MODULE	LAND USE CHANGE AND FORESTRY			
		SUBMODULE	ABANDONMENT OF MANAGED LANDS			
		WORKSHEET	5-4			
		SHEET	1 OF 3			
		STEP 1				
Regrowth Land Type		A 20 Year Total Area Aban-doned and Regrowing (kha)	B Annual Rate of Above-ground Biomass Growth (t dm/ha)	C Annual Aboveground Biomass Growth (kt dm)	D Carbon Fraction of Aboveground Biomass	E Annual Carbon Uptake in Aboveground Biomass (kt C)
				C=(AxB)		E=(CxD)
Tropical Forests	Moist					
	Seasonal					
	Dry					
Temperate Forests	Evergreen					
	Deciduous					
Boreal Forest						
Grasslands						
Other						
					Subtotal	

MODULE		**LAND USE CHANGE AND FORESTRY**						
SUBMODULE		**ABANDONMENT OF MANAGED LANDS**						
WORKSHEET		**5-4**						
SHEET		**2 OF 3**						
		STEP 2		**STEP 3**				
Regrowth Land Type		F Annual Rate of Uptake of Carbon in Soils (t C/ha)	G Total Annual Carbon Uptake in Soils (less than 20 years) (kt C)	H Total Area Abandoned More than Twenty Years (kha)	I Annual Rate of Above-ground Biomass Growth (t dm/ha)	J Annual Above-ground Biomass Growth (kt dm)	K Carbon Fraction of Above-ground Biomass	L Annual Carbon Uptake in Aboveground Biomass (kt C)
			G=(AxF)			J=(HxI)		L=(JxK)
Tropical Forests	Moist							
	Seasonal							
	Dry							
Temperate Forests	Evergreen							
	Deciduous							
Boreal Forest								
Grasslands								
Other								
		Subtotal					**Subtotal**	

MODULE		LAND USE CHANGE AND FORESTRY			
SUBMODULE		ABANDONMENT OF MANAGED LANDS			
WORKSHEET		5-4			
SHEET		3 OF 3			
		STEP 4		STEP 5	
Regrowth Land Type		M Annual Rate of Uptake of Carbon in Soils (t C/ha)	N Total Annual Carbon Uptake in Soils (kt C)	O Total Carbon Uptake from Abandoned Lands (kt C)	P Total Carbon Dioxide Uptake ($Gg\ CO_2$)
			N=(HxM)	O=(E+G+L+N)	P=(Ox[44/12])
Tropical Forests	Moist				
	Seasonal				
	Dry				
Temperate Forests	Evergreen				
	Deciduous				
Boreal Forest					
Grasslands					
Other					
		Subtotals			

MODULE 6
WASTE

6 WASTE

6.1 Introduction

This module provides methodologies for estimating emissions of CH_4 from landfills and wastewater treatment. It also suggests that the method for landfills can be adapted to estimate CH_4 from open dumps. Other types of waste disposal (e.g. incineration) will be added in future editions.

6.2 Land Disposal of Solid Waste

Introduction

This section covers estimation of emissions from sanitary landfills only, although other methods of disposal exist and may have important emissions. The method can be adapted to estimate emissions from open dumps (see box). Anaerobic decomposition of organic matter by methanogenic bacteria in landfills results in the release of CH_4 to the atmosphere. This source is estimated to account for 6-20% of global anthropogenic CH_4 emissions (IPCC, 1992).

Organic waste first decomposes aerobically (in the presence of oxygen) and is then attacked by anaerobic non-methanogenic bacteria, which convert organic material to simpler forms like cellulose, amino acids, sugars, and fats. These simple substances are further broken down to gases and short-chain organic compounds, which form the substrates for methanogenic bacteria. The resulting biogas consists of approximately 50 per cent CO_2 and 50 per cent CH_4 by volume, although the percentage of CO_2 may be smaller because some CO_2 dissolves in landfill water.

Numerous factors affect the amount of CH_4 produced in landfills. The factors may be divided into two general categories: management practices and physical factors.

The simple method for calculating emissions described here does not include time lags, but assumes that methane is released in the year in which the waste is placed in a landfills. This is not what actually occurs but gives a crude approximation of the current year emissions if the amount and composition of Municipal Solid Waste (MSW) landfilled has been relatively constant over the last five to ten years. If there have been large fluctuations over the period then the simple method will not represent the current emissions well.

The simple method is considered to produce a high estimate for a number of reasons. Detailed assessments by some OECD countries include factors such as aerobic decomposition, microbial biomass, leachate generation and methane oxidation which are not explicitly accounted for in the simple method. In an inventory by Canada which applied the simple method as well as the more complicated kinetic modelling, the more detailed method gave results which were 22 per cent lower than the simple method. Additionally, some of the factors mentioned could be more important in developing

OPEN DUMPS

For many countries, large amounts of solid waste are disposed of in open dumps, where conditions are not like those in landfills. These dumps are expected to emit less methane than landfills but still may be a significant source. The emissions can be roughly estimated using the methods for landfills and adjusting the results downward. For example, one analysis assumed that open dumps emit methane at 50 per cent of the rate from the same quantities of waste in landfills. This could be included in the worksheet by changing the "fraction of CH_4 in biogas", in step 3. In this example the default value of 0.5 for landfills would be changed to 0.25 for open dumps to reflect emissions at 50 per cent of the landfill rate. The value of 50 per cent is arbitrary and should be adjusted based on judgement of national experts. See the *Reference Manual* for further discussion.

countries where less compact disposal methods (open dumps instead of highly compacted sanitary landfill) might be employed.

Future IPCC work will focus on improving the simple method so that it is capable of accounting for time lags and the other factors mentioned above.

Data Sources

Data on Municipal Solid Waste (MSW) generation rates and percentage of MSW landfilled are available for most developed countries, and these should be used when available.

Data on waste characteristics and waste management practices for individual countries are limited in international data sources, especially for developing regions. MSW generation rates and composition for developing countries, as used by Bingemer and Crutzen (1987), are available only for major cities (e.g., Cointreau, 1984).

Furthermore, data for centrally planned economies are scarce.

For emission coefficients, we suggest using the country-specific data on MSW generation rates and landfilled amount from OECD (1989) or from the regional data developed by Bingemer and Crutzen (1987) as default factors if country-specific estimates are not available.

Table 6.1 summarises default values derived from available published literature. See the *Reference Manual* for more details about the sources of data.

Methodology - Landfills

The simple methodology allows for the calculation of CH_4 emissions based on:

a the amount of waste landfilled,

b the fraction of degradable organic carbon and the amount which actually degrades, and

c the fraction of CH_4 in landfill gas.

Completing the worksheet

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary.

Use WORKSHEET 6-1 METHANE EMISSIONS FROM LANDFILLS to enter data for this submodule.

STEP 1 ESTIMATING TOTAL MUNICIPAL SOLID WASTE LANDFILLED

1 If your country has detailed statistics on landfilled waste, enter it in column A of the main Worksheet 6-1 then go directly to Step 2.

Otherwise use the Worksheet 6-1 (Supplemental) to estimate the quantity of waste landfilled in your country.

Worksheet 6-1 (Supplemental)

a Enter total Population for the inventory year (in the case of developing countries, enter the total urban population) in column A.

b Enter the Waste Generation Rate (in annual terms) in column B.

Default values by region and for some countries are provided in Table 6-1.

TABLE 6-1
REGIONAL WASTE DISPOSAL, COMPOSITION, AND WASTE GENERATION DATA

Region	Fraction MSW Landfilled	Fraction Degradable Organic Carbon of MSW	Waste Generation Rate (kg/cap/day)	Waste Generation Rate $Gg/10^6$ persons/yr
US / Canada/ Australia	**0.91**	**0.22**	**1.8**	**657**
US	0.62	NA	2.0	730
Canada	0.93	NA	1.7	620
Australia	0.98	NA	1.9	694
Other OECD	**0.71**	**0.19**	**0.8**	**292**
Japan	0.28	NA	0.9	328
New Zealand	0.95	NA	1.8	657
Austria	0.57	NA	0.6	219
Belgium	0.50	NA	0.9	328
Denmark	0.63	NA	1.2	438
Finland	0.87	NA	1.1	402
France	0.47	NA	0.7	256
Germany	0.69	NA	0.9	328
Greece	1.00	NA	0.7	256
Ireland	1.00	NA	0.9	328
Italy	0.35	NA	0.7	256
Luxembourg	0.27	NA	1.0	365
Netherlands	0.55	NA	1.2	438
Norway	0.78	NA	1.3	474
Portugal	0.24	NA	0.6	219
Spain	0.76	NA	0.8	292
Sweden	0.42	NA	0.9	328
Switzerland	0.18	NA	1.0	365
UK	NA	NA	1.0	365
USSR/E. Europe	**0.85**	**0.175**	**0.6**	**219**
Developing Countries	**0.80**	**0.15**	**0.5**	**182**

Sources: Bingemer and Crutzen (1987) for regional data and OECD (1989) for individual countries

c Multiply Population by Waste Generation Rate to give Waste Generated. Enter the result in column C.

d Enter Fraction Landfilled in column D.

This is the fraction of total MSW which is placed in landfills expressed as a decimal fraction. Default values are provided in Table 6-1 above.

e Multiply Total Waste Generated by Fraction Landfilled to give Annual MSW Landfilled. Enter the result (in gigagrams of MSW) in column E.

f Enter the figure from column E in column A of the main Worksheet.

STEP 2 ESTIMATING THE ANNUAL RELEASE OF BIOGAS

1 Estimate the Fraction of Degradable Organic Carbon (DOC) in the MSW which is landfilled. Enter the result in column B of the main Worksheet.

Use locally available figures for the fraction if these are available. Document your sources if you do so. Some default values are included in Table 6-1.

2 Multiply Annual MSW Landfilled by Fraction DOC to give the Annual DOC Landfilled. Enter the result in column C.

3 Estimate the Fraction Which Actually Degrades in the landfill in column D.

This is the fraction of the total DOC which actually degrades in a landfill. The decomposition of DOC is not perfectly complete and some of the potentially degradable material always remains in the landfill over the long term. A default value of 0.77 is recommended, based on scientific literature.

4 Multiply Annual DOC Landfilled by the Fraction Which Actually Degrades to give the Annual Carbon Released As Biogas. Enter the result, in gigagrams, in column E.

STEP 3 ESTIMATING NET METHANE EMISSIONS

1 Enter the Fraction of carbon in biogas which is released as CH_4 and enter the result in column F.

Even in anaerobic decomposition conditions only part of the total carbon release is methane. The default value is 0.5.

Use locally available figures for the fraction if these are available. Document your sources if you do so.

2 Multiply Annual Carbon Released as Biogas by the Fraction which is methane (column F) to give Annual Carbon Released as Methane. Enter the result, in gigagrams carbon, in column G.

3 Multiply Annual Carbon Released as Methane by the Conversion Ratio in column H to give Methane Released. Enter the result, in gigagrams CH_4, in column I.

4 Enter the amount of CH_4 Recovered, in gigagrams CH_4, and used for energy in column J.

No default information is available. Use locally available figures for the amount recovered if these are available. Document your sources if you do so.

5 Subtract CH_4 Recovered from Methane Released to give Net Methane Emissions. Enter the result, in gigagrams CH_4, in column K.

6.3 Methane Emissions from Wastewater Treatment

Introduction

Treatment of wastewater streams with high contents of organic material, including domestic and commercial wastewater and some industrial wastewater streams, can emit significant amounts of methane. The IPCC (1992) estimated the total emissions from this source at 30 to 40 Tg/year, which represents 8 - 11 per cent of the total global methane emissions of 360 Tg/year.

There are two basic types of wastewater treatment which should be calculated separately. These are:

- Domestic and commercial wastewater
- Industrial wastewater

The principal factor which determines methane generation potential of wastewater is the amount of organic material in the wastewater stream. This is indicated by the Biochemical Oxygen Demand (BOD) of the wastewater, which is the amount of oxygen consumed by the organic material in the wastewater during decomposition. A standardised measure of BOD is the *5-day test* (BOD_5), expressed in milligrams per litre (mg/l).

Data Sources

Available data from international sources is summarised in Tables. See the *Reference Manual* for a detailed discussion of data sources.

Methodology

For both domestic and commercial wastewater, and for industrial wastewater the method is to estimate the amount of organic material in wastewater. Then this is multiplied by the fraction of wastewater which is anaerobically treated. The final calculation is the quantity of BOD anaerobically treated times the emissions factor, and this gives the emissions. BOD for domestic and commercial wastewater is a function of population. For industrial waste water, it is dependent on flow and industry type. This method should be viewed as a very rough first approach. Research and country-specific data collection should produce improved methods in the future.

Completing the Worksheets

Use WORKSHEET 6-2 METHANE FROM DOMESTIC AND COMMERCIAL WASTEWATER and WORKSHEET 6-3 METHANE FROM INDUSTRIAL WASTEWATER to enter data for this submodule.

Domestic and Commercial Wastewater

STEP 1 ESTIMATING BIOCHEMICAL OXYGEN DEMAND

1 Enter total population or urban population (see below) for the inventory year in column A, in 1000 persons.

Developing countries may choose to base estimates on urban rather than total population if wastes produced in rural areas decompose in an aerobic environment. See Table 6-2 for a list of aerobic and anaerobic treatment methods.

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary

TABLE 6-2
AEROBIC AND ANAEROBIC METHODS OF WASTEWATER TREATMENT

Treatment method	*Type of country*	*Details*
Aerobic	Developing Countries	• Open pits/latrines • Aerobic (shallow) ponds • Ocean dumping • River dumping
	Developed Countries	• Sewer systems with aerobic treatment
Anaerobic	Developing Countries	• Anaerobic (deep) ponds • Sewer systems with anaerobic treatment
	Developed and Developing Countries	• Septic tanks
Anaerobic with methane recovery	Primarily developed	

2 Enter Wastewater BOD Values (gigagrams/1000 persons/year) in column B.

Default values by region are shown in Table 6-3.

TABLE 6-3 ESTIMATED BOD_5 VALUES BY REGION		
Region	*BOD_5 Values* *kg/person/day*	*BOD_5 Values* *Gg/1000 persons/year*
Africa	0.037	0.0135
Asia, Middle East, Latin America	0.04	0.0146
N America, Europe, Former USSR, Oceania	0.05	0.0182
Source: US EPA 1994		

3 Multiply Population by Wastewater BOD Value to give total Annual BOD. Enter the result, in gigagrams BOD_5, in column C.

STEP 2 ESTIMATING TOTAL METHANE EMISSIONS

1 Enter Fraction of Wastewater Anaerobically Treated in column D.

Default values by region are shown in Table 6-4.

TABLE 6-4 ESTIMATED TOTAL (URBAN) WASTEWATER FRACTION ANAEROBICALLY TREATED	
Region	*Fraction Treated*
Africa, Latin America, Asia	less than 0.10
Oceania, North America, Europe	0.15
These default values are very rough approximations. Source: US EPA, 1994. Values for Africa, Asia and Latin America have been modified downward here based on comments from the Expert Group. Note: For many developing countries, industrial wastewater is often discharged with domestic wastewater.	

2 Multiply Annual BOD by Fraction of Wastewater Anaerobically Treated to give the Quantity of BOD from Anaerobically Treated Wastewater. Enter the result, in gigagrams BOD_5, in column E.

3 Enter the Methane Emissions Factor, in gigagrams CH_4/Gg BOD_5, in column F.

The recommended emissions factor is 0.22 gigagrams CH_4/gigagrams BOD_5.

4 Multiply the Quantity of BOD from Anaerobically Treated Wastewater by Methane Emissions Factor to give Total Methane Released. Enter the result in gigagrams CH_4 in column G.

STEP 3 ESTIMATING NET ANNUAL METHANE EMISSIONS

1 Estimate the amount of Methane Recovered (if any) from domestic and commercial wastewater treatment. Enter the result, in gigagrams CH_4, in column H.

2 Subtract Methane Recovered from Total Methane Released to give Net Methane Emissions. Enter the result, in gigagrams CH_4, in column I.

Industrial Wastewater

STEP 1 ESTIMATING BIOCHEMICAL OXYGEN DEMAND

1 Estimate Annual Wastewater Outflow for key industries in millions of litres and enter the result in column A of Worksheet 6-3.

If wastewater information is not directly available, outflows can be estimated based on industrial production. Table 6-5 provides typical default values in litres of water consumed per ton of product produced for some key industrial activities. As a rough estimate, water consumed is assumed to be equal to wastewater produced. Multiply the default values by domestic production statistics to estimate domestic wastewater outflow volumes.

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary

TABLE 6-5
WATER CONSUMPTION PER UNIT OF PRODUCT AT KEY INDUSTRIAL FACILITIES

Process	*Water Consumption litres/t*
Canneries	
Green beans	80,000
Peaches and pears	22,000
Other fruits and vegetables	8,000 - 40,000
Food and beverage industry	
Beer	60,000
Wine	20,000
Meat packing	16,000 - 20,000 (live weight)
Pulp and paper	
Pulp	344,000 - 966,000
Paper	200,000
Textiles	
Bleaching	300,000 - 400,000 cotton
Dying	40,000 - 80,000 cotton
Fish processing	14,000 - 20,000
Slaughterhouses	5000 (live weight)
Oil/grease	1,500 - 7,000
Soft drinks	2,500
Grain/cereals	500
Sources: Metcalf and Eddy (1992) and US EPA (forthcoming).	

2 Enter BOD Concentration by industry in column B.

Table 6-6 gives default values by industry.

TABLE 6-6
BIOCHEMICAL OXYGEN DEMAND (BOD) CONCENTRATION ESTIMATES FOR VARIOUS INDUSTRIAL WASTEWATERS

Industry	BOD_5* kg/litre
Iron and steel	0.001
Non-ferrous metals	0.001
Fertiliser	0.001
Food and beverages	0.035
Fruits and vegetables	0.003
Cereals	0.001
Meat packing	0.020
Butter	0.003
Cheese	0.003
Cane sugar	0.002
Beet sugar	0.010
Wine	0.135
Beer	0.085
Other beverages	0.083
Pulp and paper	0.004
Petroleum refining (petrochemical)	0.004
Textiles	0.001
Rubber	0.001
Fish processing	0.004
Oil and grease	0.007 - 0.031
Coffee	0.0015
Soft drinks	0.0008
Miscellaneous**	0.002

*Some of these values are "ultimate" BOD from literature. They are used as an approximation of BOD_5.

**Industries in this group were undefined.

Source: Thorneloe, 1993b.

3 Multiply the Annual Wastewater Outflow by industry by BOD Concentration to give Total BOD Generated. Enter the result in gigagrams in column C.

STEP 2 ESTIMATING TOTAL METHANE EMISSIONS

1 Enter the Fraction of Wastewater Treated Anaerobically, by industry, in column D.

Very little information is available on typical values and there is probably considerable variation across regions and industries. In developing countries, industrial wastewater is often treated with domestic and commercial wastewater. If no other information is available, use the regional default values for domestic and commercial waste in Table 6-4 as a first approximation.

2 Multiply Total BOD Generated by Fraction of Wastewater Treated Anaerobically to give the Quantity of BOD from Anaerobically Treated Wastewater. Enter the result, in gigagrams BOD, in column E.

3 Enter the Methane Emission Factor in column F.

The IPCC recommended default value for all cases is 0.22 Gigagrams CH_4 / Gigagrams BOD_5.

4 Multiply the Quantity of BOD from Anaerobically Treated Wastewater by the Methane Emission Factor to give Methane Released. Enter the result, in gigagrams CH_4, in column G.

STEP 3 ESTIMATING NET ANNUAL METHANE EMISSIONS

1 Estimate the amount of Methane Recovered (if any) from industrial wastewater treatment. Enter the result, in gigagrams CH_4, in column H.

2 Subtract Methane Recovered from Total Methane Released to give Net Methane Emissions. Enter the result, in gigagrams CH_4, in column I.

MODULE	**WASTE**
SUBMODULE	**METHANE EMISSIONS FROM LANDFILLS**
WORKSHEET	**6-1**
SHEET	**1 OF 1**

STEP 1	STEP 2				STEP 3					
A Annual MSW Landfilled (Specify sub-categories if any) (Gg)	B Fraction DOC	C Annual DOC Landfilled (Gg)	D Fraction Which Actually Degrades	E Annual Carbon Released as Biogas (Gg)	F Fraction C-CH_4 to C-Biogas	G Annual Carbon Released as CH_4 (Gg C)	H Conversion Ratio (16/12)	I CH_4 Released (Gg CH_4)	J CH_4 Recovered (Gg CH_4)	K Net CH_4 Emissions (Gg CH_4)
		C=(AxB)		E=(CxD)		G=(ExF)		I=(GxH)		K=(I-J)

MODULE	**WASTE**
SUBMODULE	**METHANE EMISSIONS FROM LANDFILLS**
WORKSHEET	**6-1 (SUPPLEMENTAL)**
SHEET	**1 OF 1**

A Population (or Urban Population) (Specify sub-categories if any) (10^6 persons)	B Waste Generation Rate (Gg MSW/10^6 persons/year)	C Waste Generated (Gg MSW)	D Fraction Landfilled	E Annual MSW Landfilled (Gg MSW)
		C=(AxB)		E=(CxD)

MODULE	WASTE
SUBMODULE	METHANE EMISSIONS FROM DOMESTIC AND COMMERCIAL WASTEWATER TREATMENT
WORKSHEET	6-2
SHEET	1 OF 1

STEP 1			STEP 2				STEP 3	
A	B	C	D	E	F	G	H	I
Population (Specify sub-categories if any) (1,000 persons)	Wastewater BOD Value (Gg BOD_5 / 1,000 persons / year)	Annual BOD (Gg BOD_5)	Fraction Wastewater Anaerobic-ally Treated	Quantity of BOD from Anaerobic-ally Treated Wastewater (Gg BOD_5)	Methane Emissions Factor (Gg CH_4 / Gg BOD_5)	Total CH_4 Released (Gg CH_4)	Methane Recovered (Gg CH_4)	Net CH_4 Emissions (Gg CH_4)
		C=(AxB)		E=(CxD)		G=(ExF)		I=(G-H)

MODULE	**WASTE**
SUBMODULE	**METHANE EMISSIONS FROM INDUSTRIAL WASTEWATER TREATMENT**
WORKSHEET	**6-3**
SHEET	**1 OF 2**

		STEP 1			STEP 2		
		A Annual Wastewater Outflow (M litres)	B BOD Concentration (kg / litre)	C Total BOD Generated (Gg BOD)	D Fraction of Wastewater Treated Anaerobically	E Quantity of BOD from Anaerobic-ally Treated Wastewater (Gg BOD)	F Methane Emission Factor (Gg CH_4 / Gg BOD_5)
				C=(AxB)		E=(CxD)	
Iron and steel							
Non-ferrous metals							
Fertiliser							
Food & Beverages	Canneries						
	Beer						
	Wine						
	Meat packing						
	Dairy products						
	Sugar						
	Fish processing						
	Oil & grease						
	Coffee						
	Soft drinks						
	Other						
Pulp and paper	Pulp						
	Paper						
	Other						
Petroleum refining/Petrochemicals							
Textiles	Bleaching						
	Dying						
	Other						
Rubber							
Other							

MODULE		**WASTE**		
SUBMODULE		**METHANE EMISSIONS FROM INDUSTRIAL WASTEWATER TREATMENT**		
WORKSHEET		**6-3**		
SHEET		**2 OF 2**		
		STEP 3		
		G Total Methane Released (Gg CH_4)	H Methane Recovered Gg CH_4	I Net Methane Emissions Gg CH_4
		G=(ExF)		I=(G-H)
Iron and steel				
Non-ferrous metals				
Fertiliser				
Food & Beverages	Canneries			
	Beer			
	Wine			
	Meat packing			
	Dairy products			
	Sugar			
	Fish processing			
	Oil & grease			
	Coffee			
	Soft drinks			
	Other			
Pulp and paper	Pulp			
	Paper			
	Other			
Petroleum refining/ Petrochemicals				
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