Use of Models and Facility-Level Data in Greenhouse Gas Inventories

Report of the IPCC Expert Meeting on Use of Models and Measurements in GHG Inventories

9-11 August 2010, Sydney, Australia

Task Force on National Greenhouse Gas Inventories

ipcc

INTERGOVERNMENTAL PANEL ON climate change

WMO UNEP

Use of Models and Facility-Level Data in Greenhouse Gas Inventories

Report of the IPCC Expert Meeting on Use of Models and Measurements in GHG Inventories

9-11 August 2010, Sydney, Australia

Task Force on National Greenhouse Gas Inventories

The IPCC would like to thank the Government of Australia for hosting this meeting and providing technical support.

Published by the Institute for Global Environmental Strategies (IGES), Hayama, Japan on behalf of the IPCC

Please cite as:
IPCC 2011, Use of Models and Facility-Level Data in Greenhouse Gas Inventories (Report of IPCC Expert Meeting on Use of Models and Measurements in Greenhouse Gas Inventories 9-11 August 2010, Sydney, Australia) eds: Eggleston H.S., Srivastava N., Tanabe K., Baasansuren J., Fukuda M., Pub. IGES, Japan 2011.

IPCC Task Force on National Greenhouse Gas Inventories (TFI)
Technical Support Unit
% Institute for Global Environmental Strategies
2108 -11, Kamiyamaguchi
Hayama, Kanagawa
JAPAN, 240-0115
Fax: (81 46) 855 3808
http://www.ipcc-nggip.iges.or.jp
Printed in Japan
ISBN 978-4-88788-075-7

Table of Contents

FOREWORD

The IPCC's Task Force on National Greenhouse Gas Inventories has, as part of its mandate, the objective of encouraging users to adopt the IPCC methodological guidelines for estimating national inventories of greenhouse gases. This report is one of a series, developed through expert meetings, which aims to assist users of the guidelines by addressing specific problem areas.

The use of higher tier methods, complex models or plant specific measurements or estimations, is becoming more widespread. However, while this has improved national inventories it is believed to have reduced transparency and therefore made the results less credible to all stakeholders. This expert meeting has brought together inventory practitioners and modellers to share their experience and to learn how they address transparency and ensure credible reporting of their inventories. The Co-chairs of the Task Force Bureau would like to thank all those involved in this meeting, and we would like to express our sincere thanks and appreciation to the Government of Australia and its Department of Climate Change for their support by hosting this meeting.

Thelma Krug

Co-Chair Task Force Bureau

Taka Hiraishi

Co-Chair Task Force Bureau

Executive Summary

The expert meeting considered experience in the use of models and measurements for all sectors in greenhouse gas emission inventories. The meeting compiled this report on experience and the lessons learnt, particularly related to transparency.

Measurements underlie both models and facility-level data. There is an increasing number of reporting systems that combine measurements made at individual plant covering all or part of specific sub-sectors. In general, models are used to estimate those emissions or removals that cannot be easily otherwise obtained, and to extend limited measurement information to cover national emissions and removals, both spatially and temporally. Models use measured data for calibration and evaluation.

The use of both models and facility-level data in inventories should be encouraged. They both provide significant opportunities to improve the overall quality through, amongst other things:

a. reducing uncertainty and improving uncertainty estimates in the national inventory;

b. improving spatial and temporal resolution of data and further disaggregating data categories;

c. improving the potential to correctly estimate impacts of mitigation on national inventories.

Transparency was identified as the key issue in the use of both models and facility-level data. The 2006 IPCC Guidelines provide the overall approach to transparently documenting and reporting these types of data. Recent experience provides useful additional guidance to inventory compilers on how to do this to increase the credibility and understanding of their results.

The meeting compiled lists of typical items that, when reported, may lead to improved transparency. These include:

Models	Facility-Level Data
• Basis and type of model • Application and adaptation of the model(1) • Main equations/processes • Key assumptions(2) • Domain of application(3) • How the model parameters were estimated • Description of key inputs and outputs • Details of calibration & model evaluation • Uncertainty and sensitivity analysis • QA/QC procedures adopted • References to peer-reviewed literature	Institutional arrangements • Legal basis • Elements covered • Criteria for data selection • QA/QC • Confidentiality(4) Category-specific • Category emissions(5) • Implied emission factor • Uncertainty • How completeness and time series consistency are ensured

Note: (1) Description of why and how the model was adapted for conditions outside the originally intended domain of application.
(2) Important assumptions made in developing and applying the model.
(3) Description of the range of conditions for which the model has been developed to apply.
(4) Description of which data are confidential, and why those were labelled as confidential.
(5) Including emissions, activity data, and emission factors, as appropriate as well as method used to generate category emissions is also included.

The meeting also considered some of the factors inventory compilers need to consider when incorporating models and facility-level data in greenhouse gas inventories.

- For models, considerations include: reasons for model selection; interpretation of model results; calibration and parameterisation; evaluation of model, processes and results; comparisons with lower tiers and measurements; uncertainty and sensitivity analysis.
- For facility-level data, considerations include: do the facility-level data definitions match those of the inventory and how has this matching been achieved; does the dataset completely cover a reporting category and if not how this gap has been filled; how has time series consistency between the facility-level data and estimates for earlier years been achieved; and how might these data enhance the quality of inventories.

The participants also noted that the use of models requires a significant, sustained and dedicated effort over the lifetime of the model to collect and update high quality and reliable data at a suitable resolution and to maintain and adapt suitable models. The main barriers to the adoption of complex models are the need for enhanced financial resources and institutional capacity. In some cases, access to suitable models, and the ability to modify them, remains a barrier to their use.

1 Introduction

The IPCC Expert Meeting on the Use of Models and Measurements in Greenhouse Gas Inventories was held in Sydney Australia on 9-11 August 2010.

The IPCC Guidelines for National Greenhouse Gas Inventories are used by parties to the United Nations Framework Convention on Climate Change (UNFCCC) to report their national greenhouse gas emissions and removals as required by the Convention. The Revised 1996 IPCC Guidelines and the subsequent Good Practice Guidance are currently adopted by the UNFCCC for reporting. The IPCC has recently updated this guidance in the 2006 IPCC Guidelines and this is currently being considered by the UNFCCC.

The 2006 IPCC Guidelines focus on providing guidance on lower level tiers, leaving nationally specific Tier 3 approaches to national inventory compilers to design and document. However, the IPCC expert meeting in Helsinki in May 2008 identified that the transparency of Tier 3 models, specifically demonstrating the comparability of models with the IPCC Guidelines, was an area where the Task Force on National Greenhouse Gas Inventories (TFI) could provide additional guidance. Subsequently the Task Force Bureau (TFB) agreed that an expert meeting should cover:

- Tier 3 models: how they should be reported and documented and how they could, in general be validated;
- Inclusion of facility-level data (both estimates and measurements, also Tier 3 approaches);
- Ensuring inventories can track mitigation efforts in a transparent way.

The meeting focused on two main areas:

- Steps to increase the perceived transparency of Tier 3 models including use, evaluation, review and documentation of models (e.g. COPERT (COmputer Programme to calculate Emissions from Road Transport), New Zealand's enteric CH_4 inventory model, CBM-CFS3 (Carbon Budget Model of the Canadian Forest Sector), modelling CH_4 emissions from rice paddies);
- Facility-level data and how they are incorporated into complete national inventories, including the use of measurements at facilities.

Invited background papers (see Annex 1) and presentations[1] exploring these topics were followed by smaller group discussions. In the light of these discussions and experience to date, the meeting compiled a report on experience and the lessons learnt, particularly related to transparency, so that inventory compilers addressing these issues can benefit from this experience.

[1] All presentations are on the TFI website: www.ipcc-nggip.iges.or.jp

2 Why use more complex methods?

Simple approaches to estimating greenhouse gas emissions and removals are often un-satisfactory because they fail to capture the complexity and diversity of systems and practices, and the resulting greenhouse gas emissions and removals. Hence, a greater number of inventories rely on more sophisticated approaches, using models or direct measurements to improve the accuracy and the resolution (both spatial and temporal) of inventory estimates.

Measurements underlie both models and facility-level data. Measurements may be made at individual plant covering all or part of specific sub-sectors, and the meeting noted that there is an increasing number of reporting systems that combine such measured data with other facility-level information. In general, models are used to estimate those emissions or removals that cannot be easily otherwise obtained, and to extend limited information to cover national emissions and removals, both spatially and temporally. Models use measured data for calibration and evaluation.

2.1 Models

Modelling is a way to increase the power of data. The 2006 IPCC Guidelines state:

> *Although models are frequently used to assess complex systems and can be used to generate data, models are means of data transformation and do not remove the need for the data to drive them.*

Chapter 2 "Approaches to Data Collection", page 2.10, Volume 1, 2006 IPCC Guidelines

Every act of data interpretation has an underlying model. Even a simple calculation such as

$$Emission = (Emission\ Factor) \times (Activity\ data)$$

is based on the assumption that units of activity individually or on the average, carry the same emissions burden. This assumption is the underlying model. More complex models are called for where this simple calculation seems inadequate e.g., the sigmoid growth of a stand of trees means that one cannot simply multiply the removal rate by the stand area to get a removal from the atmosphere; the age of the stand also matters. Linkages between processes can be much more complicated than this. This situation can of course be captured by more complex models, but the greater complexity can lead to reduced transparency. What follows is an attempt to set out experience and lessons learnt from which one can achieve greater transparency in these situations.

There are a number of benefits in using complex models in national greenhouse gas inventories. These may include:

- Models may improve coverage and completeness as those can extend existing data to improve geographic coverage/distribution and coverage of source/sink categories by filling in gaps in data.
- Models may increase spatial and temporal resolution of estimates.
- Generally, models may increase the accuracy of results and usually improve uncertainty assessment by providing a system with an improved structure and more systematic treatment of data.
- Models can provide an opportunity to test our understanding of cause-and-effect relationships, hence to assess the impacts of mitigation efforts.
- Models may provide comparability with other countries and systems.
- Models may improve transparency through stratification by making differences between strata (subcategories) explicit.
- Models may improve time series consistency of inventory, for example, by providing annual estimates even where only occasional measurements exist.
- Models may be a cost effective and in many cases the only possible option to estimate emissions and removals compared to extensive data collection.
- Models can enable better projections by matching past estimates and future projections and treatment of nationally specific circumstances, technologies and practices and mitigation efforts.
- Models can represent non-linear and dynamic systems better compared to linear averaging done in Tiers 1 and 2.

- Models can be adapted to national circumstances.
- Models can provide frameworks for uncertainty analyses and identification of research priorities to improve greenhouse gas inventories as far as is practicable.

However, using models may have some adverse effects in such cases where:

- The model is incorrectly used (e.g., applied outside the domain of application without appropriate adaptation).
- The key assumptions are not correct.
- There are errors in the model.
- Inappropriate data are fed into the model.

2.2 Facility-level data

Facility-level data may be available through a number of routes. It may have been intended as a data collection mechanism for national inventories and be supported by national legislation (e.g. the National Greenhouse and Reporting Act in Australia) or the data may be collected for another purpose but still backed by legislation (e.g. the European Union Emission Trading Scheme) or it may be collected under less formal arrangements. The utility and ease of access to the data will depend on the specific national arrangements such as: reporting requirements (including whether or not facility-level data are reported to the agency responsible for inventory preparation or to a separate regulatory authority), specification of methods to be used, QA/QC and confidentiality requirements.

Increasingly, facility-level data are becoming available to inventory compilers. They must choose whether or not to use these data; choose how to use the data; explain these choices transparently as well as transparently reporting the data. The availability of facility-level data may provide significant opportunity to reduce uncertainty in the national inventory; better reflect mitigation activities; improve the spatial resolution of data; lead to further disaggregation of categories; and improve the overall quality and accuracy of the inventory. The use of facility-level data in the national inventory should be encouraged.

2.3 The 2006 IPCC Guidelines

As noted in the overview chapter of the 2006 IPCC Guidelines, the guidelines

> *… provide advice on; i) ensuring data collection is representative and time series are consistent, ii) estimation of uncertainties at the category level, and for the inventory as a whole, iii) guidance on quality assurance and quality control procedures to provide cross-checks during inventory compilation, and iv) information to be documented, archived and reported to facilitate review and assessment of inventory estimates.*

Section 3, page 8, Overview Chapter, 2006 IPCC Guidelines

The 2006 IPCC Guidelines do provide guidance on how both data from models and facility-level data can comply with good practice when used in National Greenhouse Gas Inventories. For example Tables 1 and 2 indicate some of the specific reference in the 2006 IPCC Guidelines related to the development and use of models and the use of facility-level data, respectively.

The 2006 IPCC Guidelines also provide some information about making best use of facility-level EF data, for example

> *Comparison to plant-level emission factors: A supplementary step is to compare the country-specific factors with site-specific or plant-level factors if these are available. For example, if there are emission factors available for a few plants (but not enough to support a bottom-up approach) these plant-specific factors could be compared with the aggregated factor used in the inventory. This type of comparison provides an indication of both the reasonableness of the country-specific factor and its representativeness.*

Chapter 6 "Quality Assurance/Quality Control and Verification", page 6.13, Volume 1, 2006 IPCC Guidelines

There are also decision trees in the Stationary Combustion chapters and the Industrial Processes and Product Use to help guide the use of facility-level data.

Table 1 General Guidance related to models in Volumes 1 & 4 of the 2006 IPCC Guidelines

Section in 2006 IPCC Guidelines	Guidance
Chapter 3, Volume 1: Uncertainties	
3.2.1 Sources of data and information (p 3.14)	Guidance on uncertainties associated with models
Chapter 5, Volume 1: Time Series Consistency	
5.2.1 Recalculations due to methodological changes and refinements (Box 5.1, p 5.6)	…The calculation of emission factors and other parameters in AFOLU may require a combination of sampling and modelling work. Time series consistency must apply to the modelling work as well. Models can be viewed as a way of transforming input data to produce output results. In most cases where changes are made to the data inputs or mathematical relationships in a model, the entire time series of estimates should be recalculated. In circumstances where this is not feasible due to available data, variations of the overlap method could be applied…
Chapter 6, Volume 1: Quality Assurance/Quality Control and Verification	
6.7.1 Emissions factor QC (p 6.12)	Guidance on QC checks on models
Chapter 2, Volume 4: Generic Methodologies Applicable to Multiple Land-Use Categories	
2.5.2 Model-based Tier 3 inventories (p 2.52)	Guidance on developing model based Tier 3 inventories for AFOLU sector

Table 2 General Guidance related to facility (plant)[2] level data in Volume 1 of the 2006 IPCC Guidelines

Section in 2006 IPCC Guidelines	Guidance
Chapter 2: Approaches to Data Collection	
2.2.1 Gathering existing data, Box 2.1 (p 2.8)	Advice on filling gaps where applicable data may be unavailable or have gaps (e.g., if survey and sampling programmes may be infrequent). In these cases surrogate data can help fill gaps and generate a consistent time series or a country average. An example is provided for estimating national emissions from SF_6 from electrical equipment when only partial data are available.
2.2.2 Generating new data (p 2.8)	Guidance for generating data by measurement
2.2.3 Adapting data for inventory use (p 2.10)	Guidance on how to incorporate improved data, address incomplete coverage, combine data sets numerically, etc.
2.2.4 Emission factors and direct measurement of emissions (p 2.15)	Generic advice for the derivation or review of emission factors or other estimation parameters – "When reviewing energy or industrial plant data, it is important to ensure that the measurements are representative of the specific activity and do not include extraneous components. …"
Chapter 5: Time Series Consistency	
5.2.3 Tracking increases and decreases due to technological change and other factors (p 5.7)	… For example, an aluminium plant manager who introduces measures to reduce the frequency and intensity of anode effects may also collect plant-specific parameters that can be used to estimate a new emission factor, This new factor might not be appropriate for estimating emissions for earlier years in the time series, before the technological change occurred. In these cases it is good practice to use the updated emission factor or other estimation parameters or data to reflect these changes. …
Chapter 6: Quality Assurance/Quality Control and Verification	
6.7.1 Emissions factor QC (p 6.12)	Guidance on how to use plant-level data for QC on: Use of IPCC default EFs Use of country-specific EFs Use of direct emission measurements
6.7.2 Activity data QC (p 6.14)	Guidance on site-specific activity data QC
6.10 Verification (6.10.1 Comparisons of national estimates) (p 6.19)	Guidance on how to verify plant-specific data

[2] In the 2006 IPCC Guidelines, "plant" is used rather than "facility".

3 Use of Models in Good Practice National Greenhouse Gas Inventories

In the application of models in National Greenhouse Gas Inventories, critical issues are suitability, parameterization, calibration, evaluation, and uncertainty[3]. It is crucial that they are all reported and documented transparently in order for the model results to be understandable, assessable and credible. These issues are discussed in the 2006 IPCC Guidelines and good practice inventories will follow the approach given there. The participants noted that the most detailed discussion of the use of models is given in the AFOLU volume (Volume 4), but that the approach given there is relevant to all sectors.

There are no specific requirements for all the items needed to be reported to ensure transparency provided in the IPCC good practice guidance. Lack of transparency and inconsistent documentation was identified as a major concern by participants at this meeting. It was highlighted that a specific effort to make model results assessable by users of reported information is crucial. The participants believe that experience in the use of models in national greenhouse gas inventories has increased and this provides a basis for transparent reporting and documenting of the use of models. The participants considered that the inclusion of key elements of the model in a brief model description[4] would be one component to improve transparency. These elements are:

- Basis and type of model (statistical, deterministic, process-based, empirical, top-down, bottom-up etc.);
- Application and adaptation of the model (description of why and how the model was adapted for conditions outside the originally intended domain of application: See Section 3.1 “Suitability”) ;
- Main equations/processes;
- Key assumptions (important assumptions made in developing and applying the model);
- Domain of application (Description of the range of conditions for which the model has been developed to apply)[5];
- How the model parameters were estimated;
- Description of key inputs and outputs;
- Details of calibration and evaluation with calibration data and independent data (showing intermediate outputs at an adequately disaggregated level);
- Description of the approach taken to the uncertainty analysis and to the sensitivity analysis, and the results of these analyses;
- QA/QC procedures adopted;
- References to peer-reviewed literature (where details of the research on the model can be found).

The remainder of this chapter considers specific issues in the development, calibration and evaluation of models and, in the light of experience, indicates what should be reported in order for the model results to be transparent.

3.1 Suitability

Suitability is the applicability of model and its adaptation to the specific national situation in which the model is used for greenhouse gas inventory purposes. Where an existing model is selected inventory compilers need to consider and document the following questions:

- Is the model designed for, or portable to, the current national circumstances?

[3] For suitability, parameterization, calibration and evaluation, see Volume 1, Chapter 2 “Approaches to Data Collection” and Volume 4, Chapter 2 “Generic Methodologies Applicable to Multiple Land-Use Categories”. For uncertainty, see Volume 1, Chapter 3 “Uncertainties”.

[4] This could be described in approximately one page, and could be a hypertext document with appropriate references to data tables and literature, if possible.

[5] Model outputs should match the definitions and requirements of the IPCC Guidelines.

- Are the other conditions for which the model is applied different from those for which the model originally was developed (e.g. ecological or management)?

The documentation should include:

- The reason for choosing or designing the model (applicability);
- How the differences in local conditions compared to those for which the model was constructed were treated (e.g. ecological or management)? What are the effects these differences might have on the accuracy of model estimates?
- Is the model used outside the parameter space for which the model was developed? If yes, what might the consequences be?

3.2 Model evaluation[6]

The purpose of model evaluation is to determine its suitability for the intended use, taking into account for example the extent to which the model reproduces the variation in the data that were used to establish its parameter values. It is good practice to both calibrate and evaluate the model with independent data prior to its implementation, and to document the procedures and findings in a complete and transparent fashion.

3.2.1 Calibration data[7]

Following the establishment of the model and its calibration and parameterisation, it is good practice to compare model outputs with calibration data (step 2 in Section 2.5.2 "Model-based Tier 3 inventories" in Chapter 2, Volume 4, 2006 IPCC Guidelines). While describing the use of models for AFOLU sector 2006 IPCC Guidelines identify this

> *… is a critical step for inventory development in which model results are compared directly with measurements that were used for model calibration/parameterization (e.g., Falloon and Smith, 2002). Comparisons can be made using statistical tests and/or graphically, with the goal of demonstrating that the model effectively simulates measured trends for a variety of conditions in the source category of interest. It is good practice to ensure that the model responds appropriately to variations in activity data and that the model is able to report results by land-use category as per the conventions laid out in Chapter 3. Re-calibration of the model or modifications to the structure (i.e., algorithms) may be necessary if the model does not capture general trends or there are large systematic biases. In some cases, a new model may be selected or developed based on this evaluation. Evaluation results are an important component of the reporting documentation, justifying the use of a particular model for quantifying emissions in a source category.*

Chapter 2 "Generic Methodologies Applicable to Multiple Land-Use Categories", page 2.53, Volume 4, 2006 IPCC Guidelines

The results of this evaluation should be documented and reported.

3.2.2 Independent data

The next step in model development (step 6 in Section 2.5.2 "Model-based Tier 3 inventories" in Chapter 2, Volume 4, 2006 IPCC Guidelines) is to compare model results with independent measurements (field data). The results should be documented and reported. This is an important step in the use of models and different from the evaluation with calibration data mentioned above. The 2006 IPCC Guidelines state that:

---

[6] The meeting participants decided not to use the commonly used terms, "validation" and "verification" for these steps as these are sometimes misunderstood by the inventory compilers and model developers due to their different connotations to different user groups. Therefore these terms are not used in this chapter.

[7] There was a different opinion which argues that "calibration data" should not be used for "evaluation". Thus, there can be different views on the use of calibration data for model evaluation depending on how to define "calibration". Chapter 3 of this report is written in a consistent manner with the guidance provided in Chapter 2 "Generic Methodologies Applicable to Multiple Land-Use Categories", Volume 4 of the 2006 IPCC Guidelines.

> *…It is important to realise the difference between* [the previous section and this section] *involves testing model output with field data that were used as a basis for calibration (i.e., parameterization). In contrast, evaluation with independent data is done with a completely independent set of data from model calibration, providing a more rigorous assessment of model components and results. Optimally, independent evaluation should be based on measurements from a monitoring network or from research sites that were not used to calibrate model parameters. The network would be similar in principle to a series of sites that are used for a measurement-based inventory. However, the sampling does not need to be as dense because the network is not forming the basis for estimating carbon stock changes or non-CO_2 greenhouse gas fluxes, as in a purely measurement-based inventory, but is used to check model results…*
>
> *…In some cases, independent evaluation may demonstrate that the model-based estimation system is inappropriate due to large and unpredictable differences between model results and the measured trends from the monitoring network. Problems may stem from one of three possibilities: errors in the implementation step, poor input data, or an inappropriate model. Implementation problems typically arise from computer programming errors, while model inputs may generate erroneous results if these data are not representative of management activity or environmental conditions…*
>
> Chapter 2 "Generic Methodologies Applicable to Multiple Land-Use Categories", page 2.53, Volume 4, 2006 IPCC Guidelines

The results of this evaluation should be documented and reported.

The meeting participants emphasized the importance of following the good practice approach as outlined above by the 2006 IPCC Guidelines. In particular they agreed that these steps should cover the following points:

- Testing should cover different conditions, circumstances and spatial scales.
- Partial or component tests for the measurable parts should be performed.
- An analysis of fit of external data with model estimates is needed and should be reported.
- Evaluation of model output through model inter-comparison, if possible. This will show which models best represent local conditions.
- Evaluation of model through comparison with Tier 1/2 results. Differences between a complex model and lower tier approaches may be due to the model better representing the real world, being driven by factors that are not included in the lower tier. Therefore it is important to explain significant differences in terms of the physical processes represented in the model.

It is also important to show that the evaluation of a model considers the whole range of values (outputs) encountered.

In addition it may be possible to produce some indicators that show the model is performing correctly. Reporting such indicators and showing they are correctly conserved will demonstrate model robustness. Examples include:

- AFOLU sector models should conserve mass and land area.
- Energy sector models should be consistent with the energy balance.
- In some industrial sectors a mass balance is possible (e.g. carbon in refineries and iron and steel plant).

In addition, some intermediate outputs of the model at an adequately disaggregated level may greatly help users of reported information to assess the final outputs of the models.

3.2.3 Uncertainty and sensitivity analysis

Uncertainty and sensitivity analysis should also be performed as part of model evaluation and is important so that a rigorous measure of model confidence, based on model inputs and structure, can be reported. The error distribution of key parameters; results of either error propagation or Monte-Carlo analysis; the results of an evaluation of uncertainties with regard to uncertainties in input data and model structure and assumptions as well as the results of a sensitivity analysis or identification of key parameters/inputs to which the model outputs are more sensitive should all be reported.

3.3 Interpretation of model results

In order to assist all stakeholders in the correct interpretation of the model results, experience suggests that it would be useful to also supply, as part of the model and inventory documentation:

- A comparison of implied emission factors with either country-specific factors or, if not available, IPCC default values. This comparison should also provide an explanation for any significant differences.
- An explanation of any unusual input values and results (i.e. outliers with respect to some reference data).
- The distribution of input and output values.

4 Use of Facility-Level Data in Good Practice National Greenhouse Gas Inventories

National inventory compilers are increasingly including more facility-level data in the national inventory, particularly with the introduction of national greenhouse gas emissions reporting systems. However, experience shows that, in using facility-level data, it is critical that the national inventory compiler transparently document how their use of the facility-level data are consistent with the IPCC guidelines. One key consideration is how to transparently report the use of facility-level data in the national inventory especially regarding the data, methods and processes followed by facilities and inventory compilers and the consistency with IPCC good practice guidance.

Facility-level data may include both measured and statistical data (e.g. measured emissions and fuel consumption). Measured data may be measured emissions but can also be other emission related parameters such as fuel carbon contents, amount of CO_2 captured or mass of feedstock used. Below we outline the two key activities associated with incorporating the data into the national inventory: (1) working with the facilities to get the information needed, and (2) documenting what is done in the inventory in a transparent fashion.

4.1 Gathering facility-level data

4.1.1 Gathering facility-level data and information

The inventory compilers need to gather the following facility-level information, in order to assess how to use the data, wherever possible:

- Calculation and measurement methods used by the facility.
- Procedures for filling gaps in data from measurement systems to ensure that facility-level emissions are neither over- nor under-estimates as far as can be judged.
- QA/QC, verification, external audit activities undertaken at the facility.
- Uncertainty data collected at the facility-level.
- Determine which data are confidential, and why? Again, the regulatory program might determine what is confidential. Where not, clear procedures need to be in place to ensure that the inventory agency and the facility are in agreement as to what should be considered publicly available data and which data are confidential.
- Where a national regulatory framework governs the collection of facility-level data it may be easier to collect this information. Otherwise it may be necessary to approach facilities directly for some of this information.

4.2 Documenting facility-level information in the Inventory Report

In the previous section 4.1.1, the type of facility-level data and information to be gathered was introduced. However, it may not be practical to document all of the facility-level information gathered in the inventory report. It is important to provide sufficient data and documentation such that any external reviewer or user of the data can understand how the data have been collected and make a determination whether the methods are consistent with IPCC guidelines. The information to present can be incorporated into two places in the current inventory reports: (1) as part of a description of the institutional arrangements, and (2) as part of source category specific discussions.

4.2.1 Institutional Arrangements for data collection

To ensure transparency the inventory compiler should document the approach taken for collecting facility-level data. This should include:

- A summary discussion of any regulations governing facility-level data collection (e.g., EUETS Directives and their implementations in the Member States of the European Union, U.S. Clean Air Act, Australian National Greenhouse and Energy Reporting Act).
- Major elements of the scheme, including coverage, methods and tiers, standards followed, general QA/QC (facility-level as defined by any regulations, as well as reporting system regulators QA/QC, including audits), penalties for non-compliance, treatment of confidential data, consistency with definitions in IPCC guidelines, etc.

- Detailed information on regulations should be referenced but not fully reproduced to promote a concise but transparent report.
- Describe the general procedures in place to determine if, and if so, how, facility-level data are incorporated into Inventory (e.g., key criteria, decision trees?). These procedures should be a general discussion about the criteria, the source specific determination is discussed in the relevant source category.
- As the inventory compiler, describe additional QA/QC activities done. Refer to 2006 IPCC Guidelines for checks (e.g., implied emission factors, comparison with other Parties and external datasets, etc.)
- Describe the general treatment of confidentiality. What are the limitations on reporting due to confidentiality?

4.2.2 Category specific reporting

In the discussion about the method used to estimate emissions in each category, it is good practice for inventory compilers to provide detailed information about the source of the data. Experience has shown the following are important items to include:

- Which facility-level data did you use (AD, EF or emissions, or all of these)? What were the specific methods followed? Where emissions were used directly, it is particularly important to document how these were derived.
- What is the source specific coverage from facility-level data? If not complete, how did you estimate emissions from non-reporting facilities? If you do have coverage in the sector from your reporting regulations, but you chose not to use these data, describe why the data set used was determined to be more appropriate than the facility-level data reported.
- Source-specific data should include a commentary on:
    - ✓ Uncertainty;
    - ✓ QA/QC (e.g., comparison of implied EF);
    - ✓ Treatment of time series consistency where facility-level data only available for part of the time-series or methods changed over the time-series;
    - ✓ Where emissions are aggregated to protect confidential data, identify what data could be published (i.e. can you publish EFs for individual categories).

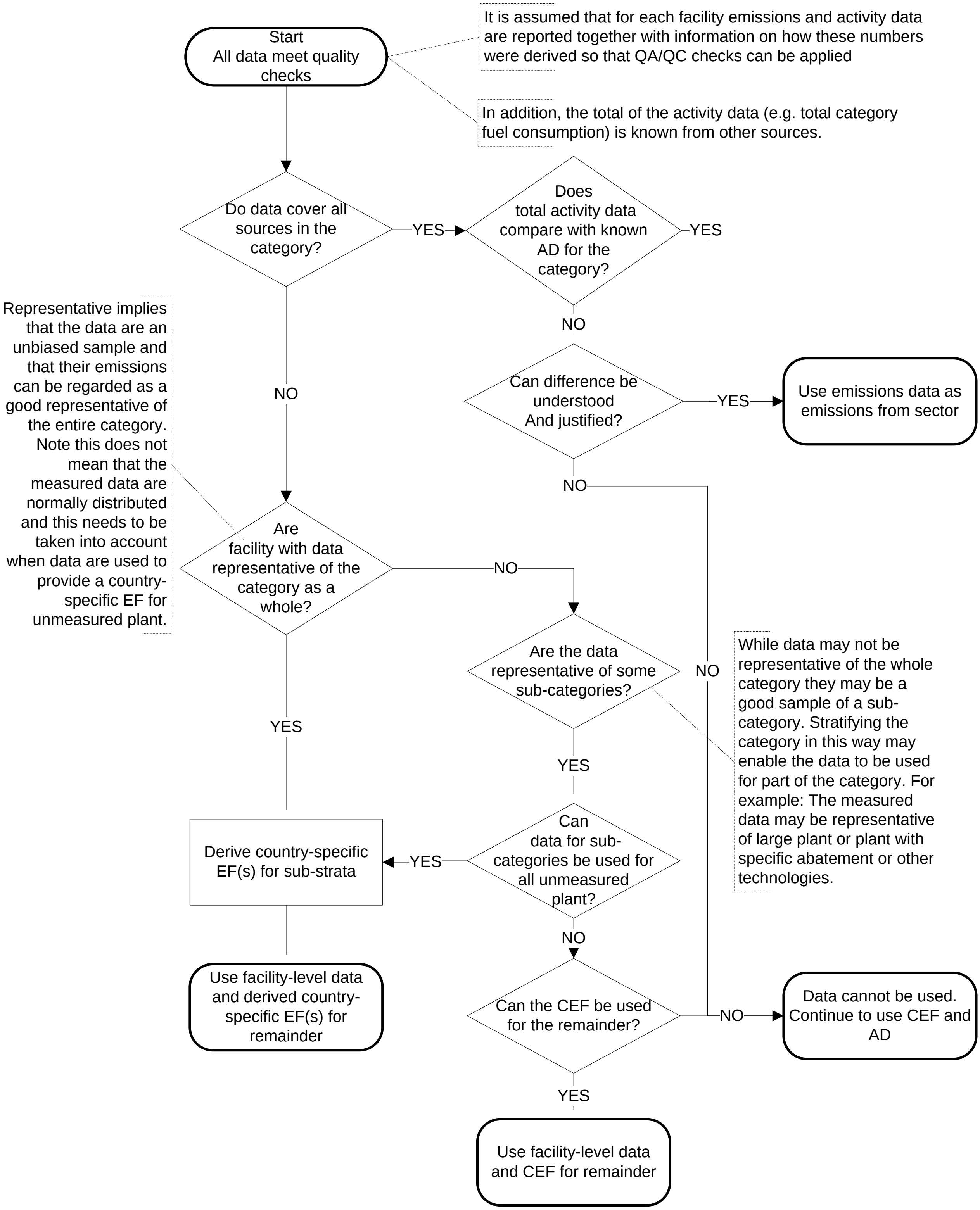
4.3 Methods of integrating facility-level data into an inventory

4.3.1 Choosing data and the criteria for selection

Based on experience to date, inventory compilers have found it is important to review facility-level data to determine if it is appropriate to incorporate it into the national greenhouse gas inventory. This is necessary as the facility-level data may cover a wide range of data qualities, may not match the inventory categories, may have an incomplete coverage, etc. Incorporation of facility-level data may be guided by an assessment of inventory quality and gaps or by the potential for facility-level data to improve the inventory. Regardless of the source of the facility-level data (e.g., whether from voluntary reporting or from an emissions trading scheme), inventory compilers should not automatically assume that such data are more accurate than the data used in an inventory and they should conduct appropriate QC checks, which may involve discussions with the operators of the facilities.

Before facility-level data can be used in the national greenhouse gas inventory, broad selection criteria should be applied to the data sets to eliminate lower quality data.

In an analogous way to the decision trees used in IPCC guidance, a decision tree could be developed to guide the choice of inventory compliers of EFs, AD and/or emissions. An example of such a decision tree is given in Figure 1.



Note:
Prior to using the facility-level data emissions from this category were estimated using a country-Specific emission factor (CEF) and activity data for the whole category (AD) known from other sources.

Figure 1 - Example of Decision Tree for Selecting Facility-Level Data

The key considerations to apply where selecting facility-level data are:

- Completeness of category coverage;
- Whether or not the use of facility-level data improves the inventory quality;
- Whether the reported emission factors and activity data are based on defaults or measured;
- Quality of measured data, sample size, representativeness;
- Ability to estimate emissions from facilities not reporting their facility-level data in order to quantify national emissions;
- The aggregation of the data (e.g. are combustion and process emission combined).

When a category is not completely covered by facility-level data an important decision is how to completely estimate the emissions from the category. Either the data cannot be used as the total category emissions cannot be estimated accurately or one of the options in Section 4.3.4 below is used.

4.3.2 Reviewing the data

Once the broad selection criteria have been applied to the facility-level data, the next step is a more detailed review of the facility-level data to enable a judgement to be made about whether they can be included in a greenhouse gas inventory. This review usually includes:

- Matching the definitions of facility categories to the IPCC source categories;
- Matching the fuels reported to the standard set of IPCC fuels;
- Where facility-level data incompletely cover a category, ensuring the ability to extrapolate to national emissions;
- Ensuring the ability to deal with incomplete time series;
- Examining the time series consistency of the data;
- Ensuring that biogenic carbon can be separated from the totals;
- Checking consistency with other sources of data (including national energy statistics).

After the review, the inventory agency can then make a judgement about whether and how the facility data can be used in the inventory.

4.3.3 Matching the definitions of source categories to the IPCC source categories

It might be possible to directly map the facility-level emissions data to a specific IPCC source category. However, in some cases the facility-level data could be a combination of several source categories in one or more sectors, for example combustion and process emissions. If these facility emissions data represent a combination of source sector emissions, this raises the question of how to make best use of these data. The inventory compliers could:

- Reject the entire facility-level data set since it does not cover a whole category.
- Use a proxy measure (e.g. facility-level energy consumption) to split the total emissions into combustion and processes emissions. If this approach is taken, clear documentation is required.

4.3.4 Treating categories with incomplete coverage by facility-level data

If the facility emissions data represent some but not all of the source category emissions, the inventory compilers need to choose how to use the data. It is important to apply a consistent decision framework across sectors. The inventory compliers could:

- Not use the facility-level data set in the estimation of emissions but the data could still be used for QA/QC.
- Devise a method to combine facility-level data with other data, where the overall accuracy of the sectoral emissions would be increased by integrating the facility-level data into the inventory (see also Section 2.2.1, Volume 1, 2006 IPCC Guidelines). There are four general possibilities when the sectoral coverage is incomplete:
    - Assume the facility-level data are representative of the whole population so the average emission rate of the facility-level data applies to any missing data;

- Assume inventory Tier 2 approach (or Tier 1 in special circumstances) is typical of the plant without specific data;
- Find a relationship between the facility-level data and some features of each facility and use this to model the emissions for facilities without data ("Surrogate Data");
- Use inventory approach to estimate category emissions and disaggregate this by facility-level data.

The choices made by inventory compilers regarding the use of facility-level data require the use of expert judgement. In some countries, steps are being taken to develop frameworks to make better use of available evidence to support these judgements and to encourage consistent decision making across sources. The IPCC plans to continue its efforts to explore and support the development of such frameworks in its future work programme.

4.3.5 Time series consistency

In general, facility-level data are not available for all inventory years. In order to achieve a consistent time series it is necessary to splice facility-level data with traditional category level estimates. The IPCC Guidelines give guidance on how to do this. (See Chapter 5 "Time Series Consistency", Volume 1, 2006 IPCC Guidelines for guidance on time series consistency, noting especially Section 5.3.3.6 "Selecting the most appropriate technique".)

The participants noted that an overlap of several years worth of data will improve the splicing of the two data sources. As additional years data are collected this splicing should be reviewed. It is also possible that as experience in the production of facility-level data improves the quality of the facility-level data may improve.

In order to recalculate earlier years data based on facility-level data, an issue to consider is the changes in technology and practices that may have occurred.

It may be the case that facility-level data are not collected annually. This could pose particular problems for time series consistency. Data collected less than annually should be reviewed carefully against the criteria outlined above and the inventory compiler should evaluate if, and if so how, the data could be incorporated into the inventory. If it is determined that it is not appropriate to use the data in the national inventory, the data may still be valuable for QA/QC.

4.4 Energy data

4.4.1 Aligning facility-level fuel and IPCC fuel types

The types of fuels reported in facility-level data may be clear, and the inventory compilers may be able to map the facility fuel data to one of the standard IPCC fuel types. In some cases, the fuels in the facility-level data may be ambiguous, and may not match the standard set of IPCC fuel types. In this case:

- Clarification could be sought from the operators of the facility about the nature of fuels being used to try and remove the ambiguity.
- A decision will need to be taken about the appropriate mapping to use between the facility-level data fuel type and the IPCC fuel type where ambiguity remains.
- Or if the ambiguity is too great, then the inventory compilers may choose not to include the facility-level data in the inventory at all.

4.4.2 Ensuring biogenic carbon can be separated

Biomass is now quite commonly used in combination with fossil fuels or indeed as a primary fuel. In Energy Sector in a national greenhouse gas inventory, CO_2 emissions from biogenic carbon should be reported as an information item separately from national total emissions. Facility-level reporting of emissions may include emissions from biogenic carbon, and so these data need careful examination to ensure that emissions from fossil fuel and biomass are correctly reported.

> **Example for EU-ETS**
>
> Emissions reported under the EU ETS should exclude emissions from bio-carbon. However, inventory compilers should be aware that the raw emissions data taken from the more detailed ETS show instances of companies reporting emissions from bio-carbon use – either these are errors in the data, or more probably they represent emissions of fossil carbon from fuels that are mixtures of bio-fuels and fossil fuels.

4.4.3 Consistency with energy statistics for the country

Estimates of emissions in the inventories often rely heavily on national energy statistics. If energy data reported from facilities were to be used in an inventory, it is important to understand the reasons for any differences between energy consumptions reported in the national energy statistics and reported via the detailed facility-level returns. This comparison may indicate under or over-allocation of fuels to sub sectors, or in the total energy balance itself. Any discrepancies should be discussed with national energy statisticians.

5 National Experience in Using Facility-Level Data

5.1 Australia: National Greenhouse and Energy Reporting Act

In Australia, a broad based mandatory reporting system has been established under the National Greenhouse and Energy Reporting (NGER) Act. The coverage of the system includes the Energy (fuel combustion), Energy (fugitive), Industrial Processes and Waste sectors and has required reporting on emissions and energy use at both company and facility levels by every major company in Australia.

A key design feature of the system has been the integration of the methods for emissions estimation for facilities and those of the national inventory ensuring consistency with IPCC guidelines and policy efficiency. As is the case with many environmental reporting systems, the risk of imposition of unsustainable compliance costs is managed through the provision of choice in the use of estimation methods by companies (apart from major components of electricity, underground coal and aluminium emissions). Measurements are undertaken at facilities (e.g., of the carbon content of fuel inputs) in accordance with Australian or international sampling and analysis standards. The system Regulator has powers of audit and significant penalties may be imposed for non-compliance.

In the national inventory, activity data collected will be used for IPCC categories where complete coverage may be obtained (electricity and many industrial process and fugitive categories) or will supplement existing data sources in other cases (stationary combustion other than electricity).

Data collected on emission factors measured at facilities will enable a shift from Tier 2 methods to Tier 3 or Tier 2 / Tier 3 mixed approaches. In the case of mixed approaches, consistent application of expert judgements across categories and over time in relation to both the use of the facility-specific data available from the NGER system and in the assumptions made for the emission factor for the uncovered portion of the category will be encouraged through the use of criteria for assessments of the representativeness of the sample of measured emission factor data, a standardised decision tree and documentation procedures.

5.2 Facility data in the Netherlands Greenhouse Gas inventory

The greenhouse gas inventory of the Netherlands is based on the national Pollutant Release & Transfer Register (PRTR). In 2000, an improvement program was initiated to transform the general process of the greenhouse gas inventory of the PRTR into a National System. Before the general process was transformed, emissions were estimated bottom-up, using facility data (average 500 companies each year) as a basis for estimating total emissions for a sector. But nowadays the emission calculations are based on energy statistics combined with company-specific emission factors (in 2008 for 20 selected companies).

Data from individual facilities are available in the form of annual environmental reports. A large number of companies have a legal obligation to submit an environmental report. Some companies provide data voluntarily within the framework of environmental covenants. The data in most of these environmental reports are used for verifying the calculated CO_2 emissions (from energy statistics) for industry, energy and refineries. Only environmental reports with high quality and transparent data are used for calculating company-specific emission factors in the Netherlands. This primarily applies to companies with deviating fuels types (residual gases, various types of coal) and / or the energy intensive industry.

Company-specific emission factors are used for 20 companies in the Netherlands (mainly refineries, electricity production and chemical industry). This means that for most sectors, only a part of the emission estimate can be based on facility data. For the part of the emission estimate which is not covered by facility data, another methodology is used. For example, if it is observed that a specific fuel type has the same composition for the entire sector, then the company-specific emission factor could be used for the entire sector. But most often, the composition of a specific fuel type varies within a sector, and in that case a country-specific emission factor (based on an average fuel composition) has been used for the remaining part of the emission estimate.

5.2.1 Responsibilities (from the Netherlands QA/QC plan)

Data are from individual companies that submit annual environmental reports (legally required or submitted within the framework of covenants). Quality of the data is the responsibility of the companies.

Competent authorities (usually those that are responsible for permits, in most cases regional authorities) are responsible for validation of the data.

Where these individual company data hold information on activity data and emissions of sufficient quality and transparency, these data are used in emission estimates.

5.3 UK facility-level emissions reporting, including Greenhouse Gas emissions

In the UK, there are a number of sources of facility-level emissions data that are used for greenhouse gas inventory compilation. This includes data collected and reported as part of the UK implementation of the EU ETS, in addition to Integrated Pollution Prevention and Control (IPPC) emissions data from regulatory agencies, and other source-specific emission estimates obtained directly from plant operators.

5.3.1 Data reported under the EU ETS

In January 2005 the European Union Emission Trading System (EU ETS) commenced operation as the largest multi-country, multi-sector Emission Trading System world-wide, initially setting up a "cap and trade" scheme for carbon dioxide emissions from high-emitting industrial sectors. The scheme is based on Directive 2003/87/EC, which entered into force on 25 October 2003. The EU ETS covers around 10,500 installations across the 27 Member States of the European Union, including the UK. Baseline data were gathered to allocate CO_2 emission allowances to installations, and operators trade allowances to balance emissions above or below their annual allocations.

Installations covered by the EU ETS are those which carry out activities listed in Annex I of the EU ETS Directive. These include energy activities, production and processing of ferrous metals, mineral industries and pulp and paper industries.

Phase I of the scheme ran from 1 January 2005 to 31 December 2007. Phase II is currently ongoing, from 1 January 2008 to 31 December 2012, with a larger scope of installations covered than in Phase I, notably in the UK where a pre-existing system of emissions trading (the UK Emissions Trading Scheme and sector-wide Climate Change Agreements) had excluded several major installations (e.g. most cement kilns) from the Phase I EU ETS.

There are EU ETS permits for 740 Installations in England and Wales, and a UK wide registry for 1,050 installations. These installations account for about 50% of UK CO_2.

Reporting under the EU ETS is installation specific, whilst reporting under the IPCC is category specific. This fundamental difference in approach between the two systems means that it has not so far been feasible to include all EU ETS data directly in the UK greenhouse gas inventory, although the EU ETS data have been used for sectoral allocation and to improve emission factors related to fuel quality.

Under the EU ETS, emissions are reported from combustion where installations have a rated thermal input exceeding 20 MW (except hazardous or municipal waste installations) as listed in Annex I to Directive 2003/87/EC and to monitor combustion emissions from other activities as listed in that Annex I to Directive 2003/87/EC where referred to in Annexes III to XI to these guidelines. For relevant processes of the petrochemical industry — if covered by Annex I Directive 2003/87/EC — Annex III may also apply.

The UK inventory agency conducts extensive quality checking of the EU ETS data, and each year seeks to resolve energy data inconsistencies between EU ETS returns and UK energy statistics by sector, and emission reporting inconsistencies, e.g. between EU ETS and IPPC returns. The EU ETS has helped to improve the accuracy of fuel use allocations across many sectors, including the mineral industries, refinery sector and iron and steel sector. The EU ETS has also provided a new resource of fuel quality measurements including CO_2 emission factors, which are now used in the UK greenhouse gas inventory.

The regulatory system governing the EU ETS in the UK includes several elements designed to ensure data quality, through a managed system of monitoring, reporting and data verification, including:

- Clear reporting templates with operator guidance provided by regulators;
- Simple permit, but detailed monitoring plans with agreed measurement and reporting tiers tailored to reflect site-specific considerations and emission allocations;
- Verification of annual operator emission returns, by independent accredited organisations.

Electronic systems have been developed for permit application and issue, annual reporting, verification, annual improvement reports, and inspections. Further details are available on the web sites of the UK Environment Agency and the UK Department of Energy and Climate Change.

The regulation of the EU ETS within the UK is managed by several Government Departments and agencies. The management of operator permits, guidance and collation of annual data submissions is regulated (on a geographical basis) by the Environment Agency of England and Wales, the Scottish Environment Protection Agency, the Northern Ireland Environment Agency and the Department of Energy & Climate Change Oil and Gas team (for offshore sites). The central management of the UK Registry for the EU ETS and submission of UK reports to the European Union Community Independent Transaction Log is governed by the Department of Energy and Climate Change.

ETS data are published on the Community Independent Transaction Log (CITL) website. Annual emissions of carbon dioxide by installation are published, alongside their annual ETS allowances. No other greenhouse gases are currently traded under EU ETS by UK installations, and the CITL data (emissions only, aggregated at site level) are of limited use for greenhouse gas inventory compilation. However, the UK Inventory Agency has secured access to the detailed ETS returns from the regulators of the ETS in the UK, and these returns provide a breakdown of emissions by fuel and process source together with supplementary information on the emission calculations. From these data, fuel carbon contents, calorific values and oxidation factors can be derived, and these may then be used in the greenhouse gas compilation, where the measurements meet quality requirements. Information on fuel carbon content is particularly valuable where operators have implemented fuel quality analytical programmes to determine carbon contents with very low uncertainties.

5.3.2 Other facility-level emissions data

There is a range of other facility-level data that are available to the UK inventory team.

Industrial plant operators submit annual emission estimates to the UK environmental agencies under the IPPC permitting regime. These data are published in the Pollution Inventory (PI) of the Environment Agency for England and Wales, the Scottish Pollutant Release Inventory (SPRI) of the Scottish Environment Protection Agency, and the Inventory of Statutory Releases (ISR) of the Northern Ireland Environment Agency. Emissions of greenhouse gases and air quality pollutants are reported, where those emissions exceed reporting thresholds (determined by pollutant) but other supporting data such as fuel use and carbon contents are not reported. Biogenic and fossil carbon emissions are not reported separately.

Other regulatory data sets include emissions reported for oil and gas producers operating on the UK Continental Shelf under the Environmental Emissions Monitoring Scheme (EEMS). EEMS provides emissions of greenhouse gas and air quality pollutants, by site and by source. Oil refinery emissions data are provided by the United Kingdom Petroleum Industry Association (UKPIA), including a detailed breakdown of greenhouse gas and air quality pollutant emissions from combustion and process sources on each refinery site. In addition, source-specific emission estimates from iron and steelworks are provided by Corus, enabling the inventory team to report emissions separately for blast furnaces, coke ovens, sinter plant, BOS plant, and other combustion and process sources.

5.4 United States Environmental Protection Agency Greenhouse Gas Reporting Program (GHGRP)

The Greenhouse Gas Reporting Program (GHGRP) requires reporting of greenhouse gas emissions and other related data from certain large downstream emissions sources, as well as suppliers of fossil fuels and industrial gases in the United States. Generally, facilities that emit equal to or greater than 25,000 metric tons of carbon dioxide equivalent ($mtCO_2e$) per year are required to submit their first annual greenhouse gas report by March 31, 2011, and annually thereafter. For some industries (e.g., cement, aluminium and ammonia production), all facilities are required to report under the program, regardless of size.

The GHGRP includes specific methods that reporters must follow to calculate and report their emissions. EPA reviewed the existing methodologies available for specific source categories, modified them as necessary to apply them at the facility-level, and developed a program that relies on use of continuous emissions monitoring systems (CEMS) for facilities that meet certain criteria (e.g., have some of the basic infrastructure and quality assurance/quality control (QA/QC) procedures already in place). Facilities not required to use CEMS must follow the facility-specific methods in the rule. In limited cases, default emission factors are also allowed.

QA/QC is an integral part of the GHGRP. The program requires facilities to use standardized calibration, certification, maintenance, and other QA/QC procedures when quantifying greenhouse gas emissions. They must document these procedures in a monitoring plan and, as appropriate, report the information to EPA or retain it as a record onsite. Once a reporter submits the data to EPA, the reporter will attest, under penalty of law, that the emissions estimates are accurate to the best of their knowledge. Data are submitted electronically. EPA will review the emissions and other supporting data submitted by reporters using electronic checks and auditing tools.

The GHGRP and the U.S. Greenhouse Gas Inventory program are managed by many of the same individuals. EPA is just beginning to identify the opportunities and challenges associated with incorporating these facility-level data into the national Inventory. The earliest that any GHGRP data could be incorporated into the greenhouse gas inventory would be with the 2012 Inventory submission (containing 2010 data). EPA intends on undertaking a careful and thorough review to ensure that incorporation of the facility-level data meets IPCC good practice guidance.

6 Enhancing the use of Models and Facility-Level Data

There are a number of practical challenges in the adoption of complex models. For example, access to higher quality and reliable data at suitable resolution is required due to their data intensity. Although requiring a lesser intensity of data than measurement systems, data must still be of relevance and of a high quality. This is a significant challenge even in developed countries where resources are less of a limitation. Even if all the data requirements can be met, there are still additional resource requirements. Sufficient institutional and human capabilities as well as enhanced resources are all needed.

Access to model and computing hardware may be an issue, however, more significantly, if the use of a model in national inventories is being considered this implies a long-term commitment in terms of collecting and updating data; developing, improving and adapting models to changing circumstances; as well as using the model itself. Creating long-term dedicated teams to work on modelling can be supported by improving coordination with research bodies and academic institutions. This can be assisted by international networks of researchers and model users, collaborative projects, a forum for exchange of information, and the development of manuals, tutorials and training workshops, to help in the transfer and portability of the model.

In addition, help could be provided to address specific issues such as access to models; documentation of the necessary changes required to apply the models in different circumstances; data acquisition; and portability of models. One suggestion was the development of more generic models applicable to a variety of conditions that could then be disseminated widely. Views differed on whether access to model source code would enhance model adaptability and transparency. Some felt that there were advantages to making source code open access, others noted that this could give rise to quality control issues if results from modified versions of models became attributed to the originators.

The two main barriers to the use of facility-level data are the need to understand the source of the underlying facility data and the completeness of the facility-level data. First, it is important to build up relationships, trust and understanding between the facilities themselves, the data collectors and the inventory compilers so that the inventory compilers can be assured that the data are appropriate for use in a national greenhouse gas inventory. Issues of concern include how the data will be used, confidentiality and QA/QC (by all parties). A second barrier to overcome is an assessment of the completeness of the facility-level data for use in a national greenhouse gas inventory. Even if facility-level data are not complete, it does not automatically mean they cannot be used in the inventory. However, in these instances, the inventory compiler will have to carefully assess whether alternative data are available to estimate emissions from facilities not covered by the facility-level data. It is important to remember that while in many cases facility-level data can improve the national greenhouse gas inventory, it may also be the case that a country's current estimates are more appropriate and the facility-level data are best used as a source of QA/QC.

7 Conclusions

The expert meeting considered the use of models and measurements in inventories. In the light of experience to date the meeting compiled this report on experiences and the lessons learnt, particularly related to transparency so that inventory compilers addressing these issues can benefit from this experience.

Measurements underlie both models (where these are for parameterisation, calibration and evaluation), and facility-level data where emissions, fuel quality or other parameters may be measured. Measurements may be made at individual plant. In general models extend information to cover national emissions and removals.

The use of both models and facility-level data in inventories can provide significant opportunity to reduce uncertainty in the national inventory; better reflect mitigation activities; improve spatial and temporal resolution of data; enable further disaggregation of categories; improve potential to correctly estimate impact of mitigation on national net emissions and improve the overall quality and accuracy of the inventory. Their use in the national inventory should be encouraged.

The key issue identified in the use of this more detailed information is transparency. While lower tier approaches are clearly documented in the IPCC Guidelines and reflect consensus of many scientists, the use of models and measurements is generally higher tier and so clear descriptions of the approaches used to derive national net emissions are needed to ensure the results are credible.

The 2006 IPCC Guidelines provide the fundamental approach to transparently documenting and reporting these types of data.

The meeting compiled lists of typical items that, when reported, may lead to improved transparency. These include:

Models	Facility-Level Data
• Basis and type of model • Application and adaptation of the model(1) • Main equations/processes • Key assumptions(2) • Domain of application(3) • How the model parameters were estimated • Description of key inputs and outputs • Details of Calibration & evaluation • Uncertainty and sensitivity analysis • QA/QC procedures adopted • References to peer-reviewed literature	Institutional Arrangements • Legal basis • Elements covered • Criteria for data selection • QA/QC • Confidentiality(4) Category-specific • Category Emissions(5) • Implied Emission Factor • Uncertainty • How completeness and time series consistency are ensured

Note: (1) Description of why and how the model was adapted for conditions outside the originally intended domain of application.
(2) Important assumptions made in developing and applying the model.
(3) Description of the range of conditions for which the model has been developed to apply.
(4) Description of which data are confidential, and why those were labelled as confidential.
(5) Including emissions, activity data, and emission factors, as appropriate as well as method used to generate category emissions is also included.

The meeting also considered some of the factors inventory compilers need to consider when incorporating models and facility-level data in greenhouse gas inventories.

- For models, considerations include: reasons for model selection; interpretation of model results; calibration and parameterisation; evaluation of model, processes and results; comparisons with lower tiers and measurements; uncertainty and sensitivity analysis.
- For facility-level data, considerations include: do the facility-level data definitions match those of the inventory and how has this matching been achieved; does the dataset completely cover a reporting category and if not how this gap has been filled; how has time series consistency between the facility-level

data and estimates for earlier years has been achieved; and how might these data enhance the quality of inventories.

The meeting also considered how the use of these methods can be encouraged. The main barriers to the adoption of complex models are the need for enhanced resources, technical capacity, computing hardware, software models and also access to high quality and reliable data at suitable resolution.

Annex 1. Example of check list for documenting the Tier 3 Model-Based Inventory developed based on the Guidance from the 2006 IPCC Guidelines

The meeting also considered how the use of these methods can be encouraged. The main barriers to the adoption of complex models are the need for enhanced resources, technical capacity, computing hardware, software models and also access to high quality and reliable data at suitable resolution.

1. Model Selection and Development
    a. Selection and applicability of model and adaptation to the situation in which the model is used for GHG inventory purposes
        i. Document choice of model based on published studies using the model for the conditions in your country and/or how the model has been adapted to represent the conditions in your country.
        ii. Supplemental documentation may be needed to describe the adaptation of the model to the conditions in a country if publications are not available with this information.
    b. Basis and type of model (statistical, deterministic, process-based, empirical, top-down, bottom-up etc.)
        i. Document the conceptual approach (e.g. model represents statistical relationships or processes), and the mathematical formulation in general terms, such as the model is process-based with a bottom-up approach to estimate emissions.
    c. Identify main processes and equations
        i. Document the main processes and describe the driving variables for those processes.
        ii. List the main equations if feasible (may not be feasible with highly complex models or not necessary with simple book-keeping models).
        iii. Also cite publications that describe the model in detail if they exist. It may be necessary to develop supplemental information documents if the model description has not been published or to provide regional parameter values that are too detailed to be publishable in a scientific journal.
    d. Key assumptions in model
        i. Document key assumptions to the extent possible (it may not be possible to list all assumptions for highly complex models).
        ii. e.g., first order approximation was assumed to represent soil organic matter decomposition for three kinetically-defined pools with a short, medium and long turnover time.
    e. Domain of application
        i. Provide information about the extent of the model application to systems in the country, e.g., all agricultural lands with arable crops grown on upland soils.
2. Model Calibration and Evaluation
    a. Calibration of the model (i.e., parameterization) may include tuning individual algorithms or the model in a single operation using informal (manual) adjustments to parameters or an automated optimization that attempts to derive a set of parameters based on minimizing the error in the predictions relative to a set of measurements.
    b. Document the model evaluation
        i. Provide graphs or other summaries of the evaluation of calibrated model to measured emissions data.
            1. Evaluation data should be from sites that were not used in calibration.
            2. Or data from the calibration sites that were collected at different time periods than the data used in the calibration step.
        ii. Other key predictions from the model may also be evaluated such as net primary production and respiration, litterfall, harvest transfers, or stock sizes which may be predicted in AFOLU sector models.
        iii. May also compare performance to other models if other models were evaluated.
    c. Include references to published articles with more detail on the calibration and/or evaluation if available. Supplemental documentation may be needed if this information is not published.

3. Identify Model Inputs
    a. Describe key inputs to the model.
        i. e.g., weather data were based on analysis of long-term precipitation and temperature data from the national weather service.
        ii. e.g., transportation data were based a national scale monitoring of miles travelled by vehicle type, engine, condition and age.
    b. Include references to publications of the input data or online publication of the data.
    c. List any key assumptions that were necessary to use these data, such as representativeness of management data.
    d. Are there special considerations with regards to the domain of the inventory application using the model given input data.
        i. e.g., were different input data sets used in different parts of the domain,
        ii. Or was the application of the model limited to specific parts of the country due to the domain of the input data.
4. Assess Uncertainties
    a. Provide a description of any sensitivity analysis conducted and a summary of findings in terms of key parameters influencing the model results.
    b. Describe the derivation of uncertainties in the model inputs and model structure, as well as any other key uncertainties.
    c. Provide references to articles that provide additional detail on sensitivity or uncertainty analysis from your application. Supplemental documentation may be needed if this information is not published.
5. Implement Model
    a. Briefly describe computing framework including the hardware, databases and programs that were used to execute the inventory.
    b. Description of key outputs variables from the model and any conversions or modifications made to derive the final emissions and removal estimates.
    c. Summary of QA/QC procedures adopted to ensure the modelling systems performed appropriately, such as conservation of land area through the analysis, unit conversions are correct, and input from experts not involved with the inventory, but reviewed the procedures, inputs and/or outputs. List any critical errors, their magnitude and implications, and corrective actions.
    d. Optionally provide examples of simple model calculations, such as emissions and removals by forest stands or landscapes in response to different forest management, natural disturbance, or mitigation scenarios. Examples of model performance may be easier to understand than lengthy and complex descriptions of intended model behaviour.
6. Evaluation of inventory results
    a. Evaluating inventory results which are determined by both the model and the input data.
        i. Estimating implied emissions factors and comparing to lower tier emission factors and/or expected ranges. Out of range values may require further explanation.
        ii. Compare to lower tier methods if inventory also estimated with lower tiers.
        iii. Compare to independent measurements that were not used in step 2 for calibration and evaluation of the model, such as data from a monitoring network in the country.
    b. Evaluate the conservation of mass through the inventory analysis, e.g., carbon or nitrogen entering the system in combination with the existing storage, is accounted for through emissions and/or storage in the system.
        i. It will be necessary to account for mass input and output including those resulting in losses of mass that are not related to greenhouse gas emissions (e.g., nitrate leaching from soils which does not contribute to direct soil nitrous oxide emissions).
        ii. Note that the system does not need to be at steady state, which occurs if inputs and outputs are equal, but storage in the system must be increasing or decreasing to balance the difference in inputs and outputs.

Annex 2. Background papers

Note 1: The following are the background papers for this presentation. They are not included in this report.

Huang, Y., Zhang, W., Zheng, X., Li, J. and Yu, Y. (2004). Modeling methane emission from rice paddies with various agricultural practices. *Journal of Geophysical Research, 109*: D08113.

Huang, Y., Zhang, W., Zheng, X., Han, S. and Yu, Y. (2006). Estimates of methane emissions from Chinese rice paddies by linking a model to GIS database. *Acta Ecologica Sinica, 26(4)*: 980−988.

Note 2: This presentation is not based on any specific background papers. Therefore no background paper is included in this report.

Issues arising from the use of Tier 3 models in AFOLU and inter-annual variability

Prof. Gary Richards

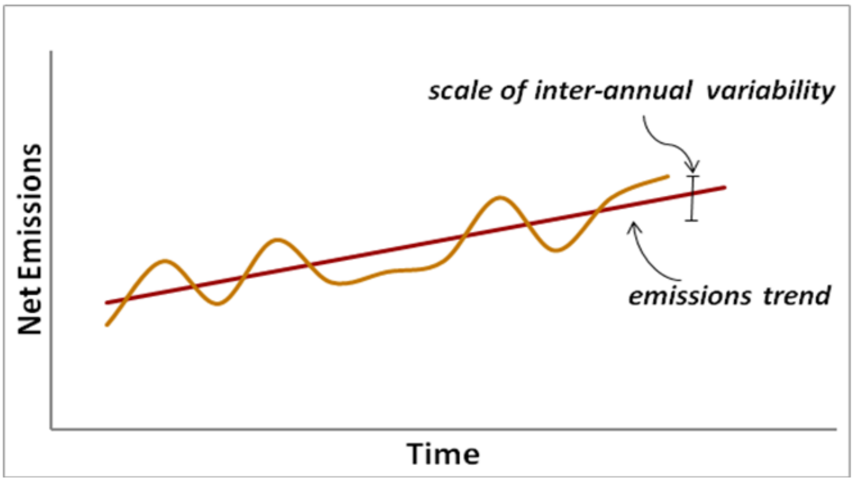
Invited Background Paper to the IPCC Experts Meeting,

Sydney, Australia, 9 – 11 August 2010

What is inter-annual variability and what causes it?

Put simply, inter-annual variability is the year-to-year change in the estimates of emissions and removals above and below an underlying trend (see Figure 1 below).

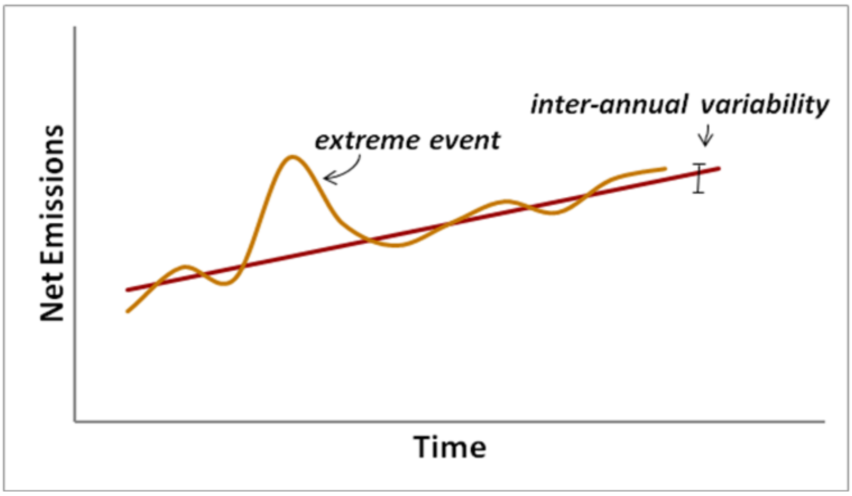
Figure 1



As the inter-annual variability in AFOLU can be greater than the trend change in any one year, or even over a short reporting period, the reported inter-annual variability can mask the underlying trend. Also, if the variability remains consistently either above or below the trend change for two or more years, it can potentially infer a false change in trend.

The extended period over which data would need to be analysed to stabilise a trend depends on both the magnitude and temporal characteristics of the variability. There may be circumstances where the variability is such that a trend cannot be confidently identified. Exacerbating the problem of determining trends in variable emissions estimates is the impact of 'extreme' results, such as emissions from very infrequent but severe events. A good example of this is wildfire. The inclusion of extreme events in emissions estimates makes it much more difficult to find an underlying trend in inter-annual variability. Figure 2 below highlights the impact that such events can have on time-series emissions data.

Figure 2



On cause of emissions, extreme events in AFOLU would typically relate to a source of emissions beyond human control, a natural disturbance such as heatwave, fire or cold-snap. Inter-annual variability could derive from either natural or human causes. For example, climate influences the rate of growth and turn-over rates in biological process. Human causes can be from changes in rates of activity driven by external factors, such as commodity prices. And of course, both human activity and biological response are not independent and can interact to either ameliorate, or by convergence, exacerbate inter-annual variability.

Why is inter-annual variability included in estimates?

The 2006 IPCC Guidelines have an implicit goal that the methods used to create estimates provide for annual estimation. The following section is on page 2.11 of Chapter 2, Volume 1 of the 2006 Guidelines, in section 2.2.3, Adapting data for inventory use.

> *Multi-year averaging: Countries should report annual inventory estimates that are based on best estimates for actual emissions and removals in that year. Generally, single year estimates provide the best approximation of real emissions/removals and a time series of single year estimates prepared according to good practice can be considered consistent. Countries should, where possible, avoid using multi-year averaging of data that would result in over- or under-estimates of emissions over time, increased uncertainty, or reduced transparency, comparability or time-series consistency of the estimates. However, in some specific cases that are described for specific sectors in Volume 2-5, multi-year averaging may be the best or even the only way to estimate data for a single year. In the case of high or uncertain annual variability – as in the growth of various tree species in a year – and where there is higher confidence in the average annual growth rate over a period of years then multi-year averaging can improve the quality of the overall estimate.*

The methods considered as good practice may (1) derive averages of multi-year estimates, (2) reflect inter-annual variability in only activity data, that is, for the human caused but not the biological variation, and (3) may fully reflect, on an annual basis, inter-annual variability in both human activity rates and biological variations due to externalities such as climate.

The way that estimates reflect inter-annual variability is therefore more to do with method chosen and measurement frequency than to do with estimation Tier. That said, Tier 3 systems more typically reflect the conjoint inter-annual variability effects of human activity and biological variations. Tier 3 models do not create inter-annual variability, they just typically provide more of a reflection of the actual inter-annual variability than Tier 3 measurement methods that use multi-year averaged inputs and reflect multi-year averaged emissions estimates.

Forms of multi-year averaging that mask inter-annual variability

Input data (activity and/or stock change/emissions estimates) can be subjected to multi-year averaging. This can be brought about by either extended measurement periods (including observations/survey, etc.) or through averaging of multiple annual measurements. While IPCC methods provide for this multi-year averaging of input data, and recommend it in some instances, there are no provisions for multi-year averaging of resultant emissions estimates.

While the reporting of actual annual estimates, and consequent inter-annual variability, is consistent with an overall goal of actual annual estimates, the multi-year averaging of input data would appear to detract from this goal.

For activity data, multi-year averaging could be brought about by:

- statistical collections, surveys etc., being conducted or reported over multiple years;
- observations, e.g., satellite data, being at a frequency exceeding a single year.

For stock changes/emissions estimates, multi-year averaging of input data can be achieved by:

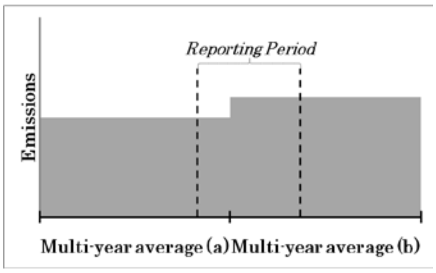
the use of emissions factors that remain static year-by-year;

- measurement programs with a return frequency of more than one year;
- use of empirical models (not driven by climate) that average responses over time; and
- use of models (driven by climate) but using long-term (greater than one year) averaged climate.

Is averaging input data the same as averaging resultant emissions estimates?

The answer to this is, probably not, but is dependent on how the input data is used. For the simplest of algorithms, the averaging of inputs may not impact on total emissions reported, but will of course impact on the time trend of emissions. This is not a concern if only the long-term total emissions are of interest. However, for reporting over short time periods this could be problematic (see Figure 3 below).

Figure 3



For any calculation method (e.g., the way forest growth data is converted to a stock or emissions estimate) that contains non-linear functions, it is also likely that neither the temporal pattern nor total emissions reported using averaged inputs will be the same as the averaged sum of actual annual emissions. Also, multi-year averaging removes the effects of extremes. For example, a period of drought followed by waterlogging does not equate to an average growth period.

The figure above shows the consequence when there is a clear representation of a multi-year average of input data e.g., when activity data is multiplied by an emissions factor more often than not various input data are averaged over different time periods. The use of such mixed provenance data needs to be approached cautiously, and specifically in the context in which it is being used.

As noted in Chapter 2 of Volume I of the 2006 Guidelines there are instances where there is merit in applying a multi-year period. The example used in the IPCC Guidelines is forest growth, where the small annual increments of growth cannot be routinely measured with certainty.

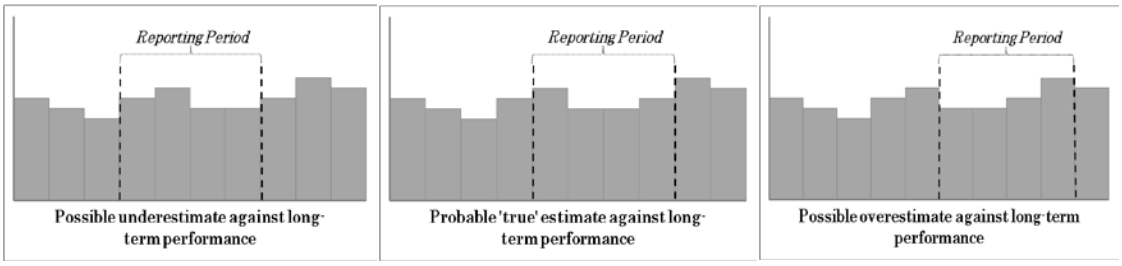
Is inter-annual variability an estimation, reporting or accounting problem?

Annual estimation of actual emissions showing inter-annual variability is not an estimation problem *per se*. However, it is not achievable using some methods, and in some instances it is less than prudent to attempt to measure small annual changes given the achievable precision of the method.

In regard to reporting, reflecting inter-annual variability can mask a trends analysis, and can also make it difficult to understand whether an annual national inventory is showing a true change in national performance. That said, if a consistent method is applied over the time-series of inventories, then the potential influence of inter-annual variability should at least be transparent. These effects are much the same for inventories using multi-year averaged inputs, where the averaging replaces the variability in masking actual annual performance.

In regard to both multi-year averaging of input data and reflecting inter-annual variability, each has problems when accounting over short periods. Figure 3 shows the problems of multi-year averaging over short periods, while Figure 4 below shows the problems encountered in accounting using inventories reflecting inter-annual variability.

Figure 4



How best to treat the problem?

Except in instances where, for the chosen method, multi-year inputs are advisable it is generally both technically prudent and transparent to treat inter-annual variability *post hoc*. This could be achieved by simple methods such as multi-year averaging as was previously applied in the 1996 IPCC Guidelines, or where appropriate models are available, provide a contrast model with the sources of variability excised, so as to determine the scale of variability.

The use of models to identify the scale of influence of externalities on emissions estimates has been considered previously by an IPCC expert workshop as a method to factor out the non-anthropogenic effects on emissions. The meeting ‘Revisiting the use of managed land as a proxy for estimating national anthropogenic emissions and removals’ (Brazil, May 2009) considered the use of Tier 3 models to provide a comparison of two time-series of emissions estimates, with and without human activities included.

In this way, there are many similarities between decisions on the treatment of non-anthropogenic emissions in natural disturbances and extreme events, and the treatment of inter-annual variability, much of which may be non-anthropogenic.

Conclusions

The IPCC 2006 Guidelines provide strong guidance on the desirability of national inventories having the “...*best approximation of real emissions/removals, and a time series of single year estimates..... Countries should, where possible, avoid using multi-year averaging of data*.....” Though pointing to cases for exception, this clarifies the desirability of both estimating and reporting actual emissions on an annual basis thereby including reflection of inter-annual variability as an estimation and reporting goal.

Though it is preferable to reflect year-to-year variability in making and reporting emissions estimates, this does create an accounting problem. When accounting considers short periods, e.g., several years, the pattern of inter-annual variability over that period could distort the outcome so as to mask a longer term trend. In this case the accounting creates a policy problem as the pattern of inter-annual variability is a form of a non-exceptional force majeure, a routine but largely unpredictable variability, mostly but not entirely beyond human control. Just as how to treat emissions from natural disturbances on managed lands has raised accounting and policy questions, so does the consideration of non-anthropogenic components of inter-annual variability.

Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) Experiences in implementing a Tier 3 approach

Werner A. Kurz

Canadian Forest Service

Natural Resources Canada

506 West Burnside Road,

Victoria BC, V8Z 1M5, Canada

e-mail: wkurz@nrcan.gc.ca

Invited Background Paper to the IPCC Experts Meeting,

Sydney, Australia, 9 – 11 August 2010

Abstract

Advanced (Tier 3) computer simulation models are increasingly used to estimate greenhouse gas emissions and removals in managed forests. Some of these model use country-specific data on forest inventory conditions, detailed activity data and process modelling approaches to link dead organic matter and soil carbon pool dynamics to those of biomass carbon pools. These Tier 3 models are expected to provide emissions and removals estimates of greater certainty than lower Tier methods. Here we briefly discuss the benefits of using Tier 3 models over simpler Tier 1 or 2 approaches, summarise approaches to evaluating such models, and propose an activity that could contribute to increasing the transparency of Tier 3 models. Increased transparency is required to facilitate the review of greenhouse gas inventories by expert review teams. In addition to improved documentation and the reporting of more detailed results using agreed-upon templates and indicators, we outline an approach that would involve a series of standardised tests and scenario analyses advancing from single stands to landscapes of increasing complexity. Indicators and performance criteria are proposed for consideration in these comparative tests. A future workshop involving model developers, model users, inventory compilers, and UNFCCC expert reviewers could focus on possible approaches to developing and implementing such testing protocols and the reporting of their results.

Background

The purpose of this paper is to advance discussion on a few issues explored in recent expert meetings of the IPCC and UNFCCC. Although not the focus of those meetings, questions arose about the benefits of using Tier 3 models, instead of Tier 1 or 2 approaches, to estimate greenhouse gas emissions and removals in managed forests. Discussions also addressed how these more complex models can be validated and made more transparent to expert reviewers.

The paper explores three questions:

1) What are the benefits of using Tier 3 models for the estimation of greenhouse gas emissions and removals in managed forests?
2) How can such Tier 3 models be evaluated?
3) How can such Tier 3 models be made more transparent to reviewers?

This paper is neither a comprehensive review nor an in-depth exploration of the issues. Instead, it is an attempt to share experiences and knowledge gained during the development and implementation of a Tier 3 model of forest carbon dynamics and greenhouse gas budgets. It also advances a proposal for a possible approach to increasing the transparency of Tier 3 models of forest carbon dynamics. The paper does not discuss Tier 3 measurement approaches.

The development of a forest carbon dynamics model for Canada commenced in late 1989 (Kurz et al. 1992), long before the UNFCCC was signed in 1992. The purpose of the research tool was to quantify the contribution of Canada's forests to the global carbon cycle. Over the past 20 years, the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) has evolved to the third version (Kurz et al. 2009, Kull et al. 2006). It is the core model of Canada's National Forest Carbon Monitoring, Accounting and Reporting System (Kurz and Apps 2006). The model is used in Canada at various spatial scales (e.g., Dymond et al. 2010; Hagemann et al. 2010; Neilson et al. 2007; Taylor et al. 2008) and in several countries around the world (e.g., Zamolodchikov et al. 2008).

CBM-CFS3 is a comprehensive book-keeping tool that relies heavily on forest inventory data and combines these with information on processes that affect forest dynamics (activity data on natural disturbances, forest management and land-use change) to estimate annual greenhouse gas emissions and removals. Process simulations are used where inventory data are limited, for example to represent the dynamics of dead organic matter and soil carbon pools. The model can be used to monitor past changes in carbon stocks (e.g. Trofymow et al. 2008, Bernier et al. 2010), using activity data of past events, or to simulate future changes (Kurz et al. 2008 a,b; Metsaranta et al. 2010), using scenario projections of future events such as natural disturbances, forest management or land-use changes.

Benefits of using Tier 3 models of forest carbon dynamics

IPCC Good Practice Guidance for Land use, Land-Use Change and Forestry (IPCC 2003) and the 2006 IPCC Guidelines National Greenhouse Gas Inventories (IPCC 2006) provide countries with the option to use Tier 3 models and approaches to estimating greenhouse gas emissions and removals in their managed forests. The use of Tier 3 models is encouraged for inventories in which forest land remaining forest land is considered a key category and where advanced methods and detailed country-specific data exist.

Tier 3 models are expected to provide estimates of emissions and removals with greater certainty relative to those calculated using Tiers 1 or 2. Tier 3 models can process more detailed, country-specific data and use more comprehensive stratifications of forest conditions by geographic regions, species, stand age, disturbance history, and management interventions.

Tier 3 models enable countries to use the best available data on processes that affect forest carbon dynamics. For example, IPCC guidelines suggest that the calculation of biomass increments consider average growth rates of different forest types. In many countries an extensive body of knowledge on growth rates has been developed through growth and yield programs that involve measurements in temporary and permanent sample plots and the development of yield tables or models from this information. Where such advanced information exists, it can replace Tier 2 type information on average growth rates by forest biomes for relevant regions or the entire country. Moreover, yield tables recognise age-dependent variations in forest growth rates as well as the impacts of species, site and forest management on forest growth. Models such as the CBM-CFS3 can accommodate libraries containing thousands of yield curves that characterise a wide range of forest conditions. While the basic approach to calculating biomass stock changes as a function of growth and losses is identical to the approach suggested by the IPCC, the number of computations and the sophistication with which forest types are stratified far exceeds what could be implemented in a Tier 2 approach that does not make use of a comprehensive book-keeping framework.

Tier 3 models enable sophisticated representation of the impacts of disturbances. Both natural and anthropogenic disturbances affect carbon stocks at the time of disturbance and in the years following disturbance. The IPCC Guidelines suggest that the differences in the impacts of disturbances on carbon stocks and their subsequent dynamics be reflected in greenhouse gas inventories. In the CBM-CFS3 we use “disturbance matrices” (Kurz et al. 1992, Kurz et al. 2009) calibrated by region, type and intensity of disturbance to summarise existing information on the immediate impacts of different disturbances on forest carbon stocks. The model also calculates delayed emissions from decomposition of biomass killed by disturbances, management activities or deforestation events.

Tier 3 models use process simulation to fill in data gaps in forest inventories. Traditional forest inventories collect little or no information on dead organic matter (DOM) and soil C pools. Knowledge of their size and dynamics is typically much more limited than knowledge of live tree biomass or volume. IPCC guidelines recommend that the dynamics of DOM and soil C pools be linked to the dynamic of the biomass pools. The rationale for this recommendation was that the changes in the DOM and soil pools are affected by the net balance of inputs and losses. Inputs originate from biomass pools through litterfall, mortality (e.g. self-thinning and stand break up), and transfers from live biomass pools associated with disturbance-caused mortality. Losses of C from DOM and soil C pools result from decomposition and disturbances (e.g., consumption of organic matter during fires, or salvage logging of dead standing trees). Processes and changes in processes that alter either input or loss rates can be represented by Tier 3 models, contributing to more accurate estimates of emissions and removals.

Tier 3 approaches use either empirical statistical relationships between stand conditions (species, age, ecological region) and DOM and soil C pool sizes (Smith and Heath 2002) or simulation of the main processes that affect pool dynamics (Kurz et al. 2009, Smyth et al. 2010, Liski et al. 2005) to account for those factors that influence greenhouse gas emissions and removals. Simulation approaches to estimating soil C stock sizes have large uncertainties because of the high variability in soil C density observed in nature. Estimates of stock changes obtained through simulation are, however, expected to have lower uncertainty because models represent the main processes that affect stock changes. Moreover, while DOM pools can change rapidly, especially during disturbances and in the years following disturbances, soil C pools are fairly stable in forest ecosystems that are not subject to land-use changes (Nave et al. 2010).

Depending on the modelling approach implemented, Tier 3 models can account for interannual variability in greenhouse gas emissions and removals in forest ecosystems. For example, models that simulate net primary production as a function of climatic conditions can estimate interannual variability in carbon removals (Richards and Brack 2004). The CBM-CFS3 uses empirical yield functions describing average growth rates, and these are not sensitive to interannual variation in growing conditions. Heterotrophic respiration (Rh) is strongly affected by variation in mean annual (and seasonal) temperature and precipitation. Tier 3 models representing these relationships can use climate data with annual variability to represent interannual variability in emissions from Rh. Tier 3 models can also account for interannual variability in human and natural disturbances. In boreal countries with extensive natural disturbances, annual area burned by wildfire can vary greatly between years and this creates large interannual variability in GHG emissions and removals (Kurz and Apps, 1999; Environment Canada 2009, Bond-Lamberty et al. 2007).

In summary, Tier 3 models are expected to yield more accurate estimates of greenhouse gas emissions and removals in managed forests than Tier 1 or 2 approaches because they use detailed country-specific data and incorporate a more comprehensive account of the main processes that govern emissions and removals.

The estimates of greenhouse gas emissions and removals are sensitive to the methods used in their derivation (e.g., Greenough et al. 1997). Quantifying how strongly such estimates are affected by the choice of methods (Tiers) would be of interest, and may further support the IPCC's recommendation that it is Good Practice to use Tier 3 methods for key categories.

Evaluation of Tier 3 models of forest carbon dynamics

Approaches to evaluation of biophysical models are discussed in the scientific literature (e.g. Bellochi et al. 2009). These usually involve comparisons of observed data and model predictions using statistical tests that assess various indicators of model performance. The challenge for models that estimate carbon and non-CO_2 greenhouse gas emissions and removals for forested landscapes is that these fluxes are not readily measured over large landscapes. There are, however, a number of options to evaluate components of such models.

1 Plot or stand-level evaluation

Tier 3 model predictions can be compared with measurements of carbon stocks and stock changes at the plot or stand level (e.g. Hagemann et al. 2010, Moroni et al. in press, Taylor et al. 2008). Where repeated measurements of C stocks in the same plot have been conducted, these can be used to assess model estimates of stock changes. In forestry, many measurements of changes in stand biomass (or volume) exist but measurements of C stock changes in dead organic matter and soil C pools are less abundant because of the high expense of such measurements when made with the appropriate precision.

Ecological studies often measure plot-level component fluxes, such as foliage and needle litter fall or the turnover of biomass components such as branches or fine roots. Where such processes are represented in Tier 3 models, field measurements can be used to compare model estimates of component fluxes. Similarly, studies of biomass removals during forest harvest, or fuel consumption during wildfires, can be used to compare model estimates of component fluxes.

Long-term ecological studies of decay rates are sometimes available to parameterise decomposition algorithms in Tier 3 models (e.g. Trofymow et al. 2002; Smyth et al. 2010). Rarely, however, will there be data from a second independent long-term study that could be used in a validation exercise. Instead, models can be applied at the plot level with the parameterisation developed from long-term studies to predict the dead organic matter pool sizes. Comparing, for a wide range of plot conditions, the model predictions against field measurements is one way to evaluate components of Tier 3 models. Obtaining long-term experimental data for slowly decomposing pools, such as coarse woody debris, or difficult to study components such as coarse roots, remains a major challenge for model evaluation.

2 Evaluation at scale of small landscapes

Comparisons against other stand- or landscape-level models also offer opportunities to assess Tier 3 model estimates of component fluxes or ecological indicators such as Net Primary Production (NPP) and Net Ecosystem Production (NEP).

Validation can be conducted at the scale of small landscapes, where inventory data are compiled at two or more points in time (e.g. Trofymow et al. 2008, Bernier et al. 2010). Such intensive studies of landscape-level carbon stock changes cannot effectively be conducted for large landscapes but demonstrating at smaller scales that the Tier 3 models adequately describe temporal dynamics of carbon stocks is a very useful evaluation exercise.

Direct measurement of CO_2 fluxes using eddy-covariance towers is another approach to validating Tier 3 models. However, care must be taken to adequately describe the tower footprint from which flux estimates are measured and ensure that the models simulate the same area (Chen et al. 2009). Tier 3 models used to estimate and report forest greenhouse gas balances typically operate on monthly or annual time scales that are less well suited for comparison against flux tower estimates obtained at much higher frequency. But if uncertainties about cumulative annual NEP estimates derived from tower measurements and those estimated using the models are quantified, such comparisons can be highly instructive. Under some circumstances, data collected by tree-ring based reconstruction (Metsaranta and Lieffers 2009) can also be used as an independent data set for comparing both Tier 3 models and flux measurements made at eddy-covariance towers.

3 Regional or national-scale evaluation

Currently it is not possible to evaluate estimates of emissions and removals at the scale of large regions or at the national scale for several reasons:

First, emission and removal estimates for UNFCCC reporting are intended to focus on anthropogenic causes and therefore exclude fluxes from unmanaged lands. Even if it were possible to measure regional fluxes, the contributions of unreported sources and sinks to regional fluxes would have to be determined before comparing reported flux estimates from Tier 3 models against regional flux measurements.

Second, models used for GHG inventory reporting often operate on time scales much longer (e.g. monthly or annual time steps) than observations of regional fluxes.

Third, independent estimates of regional sources and sinks, e.g. from inverse modelling are increasingly uncertain with decreasing size of the region for which fluxes are estimated. With present scientific knowledge (and the sparse network of atmospheric CO_2 observations available for use by inversion models) the estimates of regional GHG fluxes from inversion models serve to constrain estimates from regional forest C dynamics models, but results from inversion models are still too uncertain to evaluate forest carbon dynamics models.

In summary, while evaluation of Tier 3 models may at times be difficult, it is important to emphasise that evaluation of estimates obtained from Tier 1 or Tier 2 approaches is even more difficult because these typically lack the detailed information that would enable comparison of component fluxes. Moreover, Tier 1 and 2 approaches lack the detailed stratification of forests into region, species, stand types, age-classes and other characteristics that enable comparisons against field measurements of forest attributes within these strata.

Increasing transparency of Tier 3 models of forest carbon dynamics

Expert review teams in the UNFCCC process face the challenge of having to review Tier 3 models used to estimate emissions and removal in managed forests. Tier 3 approaches are typically more complex and more data intensive than Tier 1 or 2 approaches. Because complex models are often perceived as “black boxes” there have been calls for increased transparency and efforts that facilitate the understanding and review of Tier 3 models.

Scientific acceptance of Tier 3 models relies on peer-reviewed publications and other reports that describe in detail the processes, equations and algorithms incorporated in the models. While such publications are essential, they are not sufficient to increase the transparency of models for reviewers with limited time to conduct reviews of country submissions. Moreover, methods used in models cannot be fully described in the space alloted for method descriptions in most academic journals: this can preclude detailed examination of parameters at the spatial or temporal scales relevant to GHG inventories.

There is a need to improve the documentation of Tier 3 models to facilitate their review by expert review teams. It may be possible to develop, in consultation with reviewers, templates or tables (fact sheets) summarising the type of information that reviewers would like to see reported. Common Reporting Format (CRF) tables developed primarily for Tier 1 and Tier 2 approaches are one step in that direction: additional information reported in a standardised form for Tier 3 models would, however, be helpful. For example, summary statistics on yield table assumptions, graphs on net ecosystem production as a function of stand age and past disturbances, estimates of NPP and NEP by forest type and age, GHG emissions associated with different disturbance types, and other indicators could be compiled and reported in ways that allow for easier comparison between Tier 3 models. Examples that document how Tier 3 models represent the stand-level impacts of human activities on emissions and removals could also be provided to document which mitigation options can, and cannot be simulated in Tier 3 models of various types. And lastly, even simple fact sheets that summarise the type of modelling approaches, the types of input data used and model limitations may help to increase reviewer comfort with Tier 3 models.

It has been suggested that, in addition to supplying adequate documentation of the model scope, algorithms, and data used, providing the computer source code of models would increase transparency for reviewers. Tier 3 models and their user interfaces are often built using many thousands of lines of computer code, and it is highly unlikely that reviewers of greenhouse gas inventories would be able to invest the time required to understand the inner workings of a computer model based on the review of source code.

What alternatives are available to increase the transparency of Tier 3 models of forest carbon and non-CO_2 emissions and removals?

A proposal to increase transparency of Tier 3 forest carbon dynamics models

One approach to increasing the transparency of Tier 3 forest carbon dynamics models could be to document their estimates of C stocks, and more importantly stock changes, using a set of standard data sets and scenarios that each model has to analyse. Analytical laboratories routinely use standard reference samples to test the calibration of equipment and the sample processing procedures and to compare estimates obtained from different laboratories for the same standard samples. Similarly, it should be possible to test the behaviour of Tier 3 model against standardised data sets and model scenarios. The rationale for this proposal is that in addition to improved documentation of the inner workings of Tier 3 models, the concern about “black boxes” can be alleviated by clearly documenting model behaviour and performance. Documenting model results for standard tests using agreed-upon indicators and performance evaluation criteria is expected to increase reviewers’ confidence in Tier 3 models.

Implementation of this proposal would require the compilation of data sets and scenario assumptions for some hypothetical stands and forest landscapes for selected biomes (boreal, temperate), forest types, and management intensity (natural forests, plantations). Standard tests could range from simple, stand-level simulations to progressively more complex scenarios of forest dynamics and land-use changes at the landscape scale. The development of a series of stand- and landscape-level scenarios could start with simple stand-level simulations of basic forestry operations such as clear cut logging and subsequent recovery. More complex simulations could involve tens of stands with simple forest management activities and natural disturbances such as wildfire. Even more complex simulations could represent land-use changes from forest to non-forest land uses, with reporting of emissions and removals by land category. And finally large data sets involving hundreds or thousands of stands could be provided for standardised tests.

Implementation of this proposal would also require the identification of a series of indicators that would be used to evaluate model performance. These could include:

Annual per hectare and total C amounts in each of the five ecosystem carbon pools identified by the IPCC guidelines (and possibly more pools if this would enhance the ability to compare models);

- information on area and area changes in each of the six UNFCCC land categories;
- estimates of Net Primary Production, Net Ecosystem Production and Net Biome Production;
- emissions and removals of CO_2 and non-CO_2 greenhouse gases by land category and year, and
- other relevant indicators related to activities such as annual transfers of harvested carbon from ecosystems to the forest product sector.

A number of technical issues would have to be resolved, such as how to provide data in formats that they can be readily imported by a number of Tier 3 models. Auxilliary data such as climate and other environmental parameters for the hypothetical landscapes would also need to be developed and provided to those models that use such information.

Tier 3 model results can then be compared against “known” estimates derived from the hypothetical examples. Criteria for the evaluation of model performances would also be required. For example, these could include (seemingly) simple rules such as:

1) Conservation of area: during a landscape-simulation the area included in the project must not change (i.e. the sum of the area in all land categories is “constant”).
2) Conservation of mass: the sum of the reported fluxes of carbon must be consistent with the combined differences in carbon stocks. Models must neither loose nor gain carbon without accounting for the underlying fluxes and transfers.

3) No transitions in and out of land-use categories must occur unless these are specified by the activity data on land-use changes or by other rules of the IPCC guidelines (i.e. time-dependent transitions between land categories: cropland converted to forest land becomes forest land remaining forest land after 20 years).

A number of more complex rules can be developed that can become part of the standardised testing procedure.

Finally, criteria for pass or fail of standardised tests would be useful to summarise the overall test results.

Comparison of results from several Tier 3 models will also be of scientific interest as it may allow model developers to identify discrepancies between models, which in some cases can be indications of errors in algorithms or parameterization, or of unintended model behaviour (Smith et al 1997). This may motivate the participation in such a process by model developers.

The administration of such tests and the reporting of results to the UNFCCC community of expert reviewers could be undertaken collaboratively between model developers and independent experts. Input data files, the executable model, as well as results should be archived and made available to the testers and expert reviewers.

The development of standardised testing protocols and the required data sets is likely to be an iterative process that could involve more than one round of exploration and feedback from both the modelling and the reviewer communities. This is not a short-term solution to increasing Tier 3 model transparency because it will require considerable effort to implement and test. A future workshop of IPCC experts, model developers, model users, inventory compilers, and UNFCCC expert reviewers could focus on possible approaches to implementing such testing protocols. Coordinators will be required who manage the development and implementation process.

Comparing Tier 3 models of forest carbon dynamics using standardised tests, scenarios and performance criteria may be one effective way to increase the transparency of Tier 3 models. Such tests can augment peer-reviewed scientific publications, model documentation, and detailed reporting of model results in agreed-upon templates.

Acknowledgements

I thank Juha Metsaranta, Graham Stinson and Dominique Blain for helpful comments on a draft of this manuscript.

References

Bellochi G, Rivington M, Donatelli M, Matthews K, 2009 Validation of biophysical models: issues and methodologies. A review, Agron. Sustain. Dev. DOI: 10.1051/agro/2009001

Bernier PY, Guindon L, Kurz WA, Stinson G, 2010. Reconstructing and modelling 71 years of forest growth in a Canadian boreal landscape: a test of the CBM-CFS3 carbon accounting model. Can. J. For. Res. 40: 109-118

Bond-Lamberty, B, Peckham SD, Ahl DE, Gower ST, 2007. Fire as the dominant driver of central Canadian boreal forest carbon balance. Nature 450: 89-92.

Chen B, Black TA, Coops NC, Hilker T, Trofymow JA, Morgenstern K, 2009. Assessing Tower Flux Footprint Climatology and Scaling Between Remotely Sensed and Eddy Covariance Measurements. Boundary-Layer Meteorol DOI 10.1007/s10546-008-9339-1.

Dymond CC, Neilson ET, Stinson G, Porter K, MacLean DA, Gray DR, Campagna M, Kurz WA, 2010. Future Spruce Budworm Outbreak May Create a Carbon Source in Eastern Canadian Forests. Ecosystems. DOI 10.1007/s10021-010-9364-z

Environment Canada 2009. National Inventory Report 1990-2007. Greenhouse Gas Sources and Sinks in Canada. The Government of Canada's Submission to the UN Framework Convention on Climate Change. www.ec.gc.ca/ghg

Greenough JA, Apps, MJ, Kurz WA, 1997. Influence of Methodology and Assumptions on Reported National Carbon Flux Inventories: An Illustration from the Canadian Forest Sector. Mitigation & Adaptation Strategies for Global Change 2: 267-283.

Hagemann U, Moroni MT, Shaw CH, Kurz WA, Makeschin F 2010 Comparing measured and modelled forest carbon stocks in high-boreal forests of harvest and natural-disturbance origin in Labrador, Canada. Ecol. Modelling 221:825-839

Intergovernmental Panel on Climate Change (IPCC), 2003. Penman, J., et al. (Eds.), Good Practice Guidance for Land Use, Land-Use Change and Forestry. Institute for Global Environmental Strategies, Hayama.

Intergovernmental Panel on Climate Change (IPCC), 2006. Eggleston, S., et al. (Eds.), Guidelines for National Greenhouse Gas Inventories. Institute for Global Environmental Strategies, Hayama.

Kull SJ, Kurz WA, Rampley G, Banfield GE, Schivatcheva RK, Apps MJ, 2006. Operational-Scale Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) Version 1.0: User's Guide. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta.

Kurz WA, Apps MJ, Webb TM, McNamee PJ, 1992. The carbon budget of the Canadian forest sector: phase I. Forestry Canada, Northwest Region. Information Report NOR-X-326, 93 pp.

Kurz WA, Apps MJ, 1999. A 70-year retrospective analysis of carbon fluxes in the Canadian forest sector. Ecol. Appl. 9, 526–547.

Kurz WA, Apps MJ, 2006. Developing Canada's National Forest Carbon Monitoring, Accounting and Reporting System to meet the reporting requirements of the Kyoto Protocol, Mitigation and Adaptation Strategies for Global Change, 11: 33–43.

Kurz WA, Dymond CC, White TM, Stinson G, Shaw CH, Rampley GJ, Smyth C, Simpson BN, Neilson ET, Trofymow JA, Metsaranta J, Apps MJ, 2009, CBM-CFS3: a model of carbon-dynamics in forestry and land-use change implementing IPCC standards, Ecological Modelling 480-504.

Kurz WA, Dymond CC, Stinson G, Rampley GJ, Neilson ET, Carroll AL, Ebata T, Safranyik L, 2008a, Mountain pine beetle and forest carbon feedback to climate change, Nature 452:987-990,

Kurz WA, Stinson G, Rampley GJ, Dymond CC, Neilson ET, 2008b, Risk of natural disturbances makes future contribution of Canada's forests to the global carbon cycle highly uncertain. Proceedings of the National Academy of Sciences, 105: 1551-1555.

Liski J, Palosuo T, Peltoniemi M, Sievänen R, 2005. Carbon and decomposition model Yasso for forest soils, Ecol. Model. 189: 168–182.

Metsaranta JM, Kurz WA, Neilson ET, Stinson G, 2010 Implications of future disturbance regimes on the carbon balance of Canada's managed forest (2010-2100). Tellus B (early online version).

Metsaranta, JM and Lieffers VJ 2009. Using dendrochronology to obtain annual data for modelling stand development: a supplement to permanent sample plots. Forestry 82:163-173

Moroni, MT, Shaw CH, Kurz WA, Rampley GJ, in press, Forest Carbon Stocks in Newfoundland Boreal forests of harvest and natural disturbance origin II: Model Evaluation, Can. J. For. Res. In press.

Nave LE, Vance ED, Swanston CW, Curtis PS, 2010. Harvest impacts on soil carbon storage in temperate forests, Forest Ecology and Management 259: 857–866.

Neilson ET, MacLean DA, Meng F-R, Arp PA, 2007. Spatial distribution of carbon in natural and managed stands in an industrial forest in New Brunswick, Canada. For Ecol Man 253: 148-1160.

Richards G, Brack C, 2004. A continental biomass stock and stock change estimation approach for Australia. Australian Forestry 67: 284–288.

Smith, JE, Heath LS, 2002. A model of forest floor carbon mass for United States forest types. Res. Pap. NE-722. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 37 p.

Smith P, Smith JU, Powlson DS, McGill WB, Arah JRM, Chertov OG, Coleman K, Franko U, Frolking S, Jenkinson DS, Jensen LS, Kelly RH, Klein-Gunnewiek H, Komarov AS, Li C, Molina JAE, Mueller T, Parton WJ, Thornley JHM, Whitmore AP, 1997. A comparison of the performance of nine soil organic matter models using datasets from seven long-term experiments, Geoderma 81: 153-225.

Smyth CE, Trofymow JA, Kurz WA, CIDET Working Group, 2010. Decreasing uncertainty in CBM-CFS3 estimates of forest soil carbon sources through use of long-term data from the Canadian Intersite Decomposition Experiment. Victoria (BC): Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre. Information Report BC-X-422.

Taylor AR, Wang JR, Kurz WA 2008. Effects of harvesting intensity on carbon stocks in eastern Canadian red spruce (Picea rubens) forests: An exploratory analysis using the CBM-CFS3 simulation model. For Ecol Man 255:3632-3641.

Trofymow, JA, Moore, TR, Titus, B, Prescott, C, Morrison, I, Siltanen, M, Smith, S, Fyles, J, Wein, R, Camiré, C, Duschene, L, Kozak, L, Kranabetter, M, Visser, S, 2002. Rates of litter decomposition over 6 years in Canadian forests: Influence of litter quality and climate. Can. J. For. Res. 32:789-804.

Trofymow JA, Stinson G, Kurz WA, 2008. Derivation of a spatially explicit 86-year retrospective carbon budget for a landscape undergoing conversion from old-growth to managed forests on Vancouver Island, BC, Forest Ecology and Management 256: 1677–1691, doi:10.1016/j.foreco.2008.02.056.

Zamolodchikov DG, Grabovsky VI, Korovin GN, Kurz WA, 2008. Assessment and forecast of carbon budget in forests of Vologda Region using the Canadian Model CBM-CFS, Lesovedenie (Forest Science) 6: 3-14 (in Russian).

New Zealand's enteric methane/nitrous oxide inventory model and the New Zealand Emissions Trading Scheme

Dr. Andrea Pickering

Ministry of Agriculture and Forestry

New Zealand

Invited Background Paper to the IPCC Experts Meeting,

Sydney, Australia, 9 – 11 August 2010

Introduction

Under the Kyoto protocol New Zealand has an obligation to reduce greenhouse gas emissions during the first commitment period (2008 – 2012) to 1990 levels. As part of the New Zealand Governments strategy to reach this goal an Emissions Trading Scheme (ETS) has been introduced. New Zealand agriculture is the largest single sector contributing to total emissions in New Zealand, and in 2008 the sector accounted for 46.6% of New Zealand emissions (Ministry for the Environment, 2010). Therefore developing a transparent ETS methodology which is in line with Inventory report is vital for the agricultural sector.

This paper describes the tier 3 Inventory model used by New Zealand to estimate the emissions from the agricultural sector; the benefits of this model over a tier 2 approach; validation, documentation and transparency of the model; and how the model was used to develop ETS emission factors for the agricultural sector.

The New Zealand inventory model

New Zealand currently uses a model to estimate emissions from the key livestock categories in the agricultural sector. These categories are dairy cattle, beef cattle, sheep and deer and they made up 93% of all of New Zealand's agricultural emissions in 2008. Nitrogenous fertiliser, crop residue, savannah and crop burning, and minor species (poultry, swine, horses, goats and alpaca and llamas) use a tier 1 methodology that employs country specific emission factors for nitrous oxide estimations.

Relationship to inventory guideline methods

The algorithms used in the New Zealand Inventory model to determine energy requirements of different livestock categories are similar in concept to that suggested in the IPCC good practice guidelines Tier 2 methodology. However, as nearly all of New Zealand's livestock are pasture fed, their emissions per unit of feed intake will differ compared to livestock which are grain fed. Also, manure is generally deposited directly onto pasture while grazing, reducing the amount of manure management carried out in New Zealand. Therefore the Inventory model uses algorithms and methods developed specifically for animals which are pasture fed to account for these differences. On going research into methane emissions from New Zealand livestock, using calorimeters and precise feed intake estimates continue to be fed into the Inventory model to verify and improve the emissions estimations for New Zealand Agriculture.

As recommended in the IPCC good practice guidelines, livestock are divided into relatively homogenous groups. Livestock population categories are determined by population models for each species. The models use livestock population data collected through agricultural production surveys collected by Statistics New Zealand on an annual basis. This population data is a snap shot of the livestock population in New Zealand for various categories at one point in time. The model uses this population data and predicts livestock age, sex and physiological stage on a monthly basis. New Zealand farming practices including birth dates, time of slaughter, death rates, movement between age groups etc are all used in the population model.

The Inventory model then uses the monthly populations and statistical data on production (weight, milk and wool production etc) to "grow" an animal in each category and determine monthly dry matter intake. Dry matter intake is based on estimated monthly energy requirements (for weight gain, gestation, milk, wool etc), and monthly feed energy concentration, digestibility and N concentration. From these feed intake estimations monthly methane emissions and nitrogen excretion are determined. Emissions are then added together to obtain annual emissions for an animal in each livestock category.

Benefit of model over tier 2 approach

Accuracy

By modelling populations on a monthly basis the variations in livestock categories throughout a year and the change in production at an individual animal level can be accounted for. Animals weight and production levels do not stay consistent over a year and by assuming this there is a risk of either over or under estimating subsequent emissions. By modelling monthly growth and production through out the year, and then determining the energy requirements over this smaller time interval, a more accurate picture of the emissions produced from livestock can be obtained.

Changes in the natural environment throughout the year can be incorporated into the calculations. This is more important in pasture feed situations where the quality of feed changes through out the year. For example, currently monthly estimates of feed energy concentration, digestibility and nitrogen content are factored into the calculations. These values are based on historic pasture samples taken through out the year, but there is currently limited information on how this may change from year to year. Research is continuing in this area and in the future it will be possible to include actual real time measurements of these three variables from satellite imagery. This will allow measurements of feed quality on a monthly basis, at a regional level and can incorporate changes from year to year. Development of this improvement has been more problematic than it may be in other countries due to the large amount of cloud cover over New Zealand at certain times. This has restricted the speed at which verification of a relationship between the imagery and actual pasture measurements has been able to occur.

In the latest Inventory the model was further developed to estimate dairy emissions on a regional basis using regional productivity data. Therefore the differences in dairy productivity among regions can now be used to improve the accuracy of the model. This was achievable through very concise dairy productivity data dating back to 1990. The population model for dairy can now be improved so that regional differences can be incorporated. For example calving date, milk production curves etc. The differences in feed quality among regions will also be able to be incorporated once available, further improving the calculations.

Comparability

Using a model to calculate emissions from New Zealand agriculture means that emissions can be determined for a calendar year. Population data fed into the model is a snap shot of the population at one point in time in the year. This point in time is the end of June, which the end of the financial year for many farming business's but is the middle of the calendar year. By using this information and estimating populations on a monthly basis, the months can then be aggregated into a calendar year. This results in an Inventory which is comparable with other countries.

Validation, documentation and transparency.

It is important that the models used in the calculation of emissions from livestock are transparent so that they are easily validated and reviewable. With further disaggregation of data and categories and changes to methodologies that require increasing amounts of activity data, producing consistent time series may become more difficult as the methodology moves away from the current pool of existing data dating back to 1990. Methods of extrapolating data in the IPCC guidelines will need to be implemented, including expert judgment and predicting data from existing information.

Validation

As agriculture is such a large component of the New Zealand Inventory, research in this area is ongoing and extensive. Results are continually fed into the model in order to improve model outputs. This includes further research in calorimeters to improve the estimation of methane emission from different livestock categories. The original development of the model was based on extensive livestock emission research which is peer reviewed and published in scientific journals. The incorporation of new research into the model also requires international peer reviews. Suggested changes are presented to an expert advisory panel which assesses the robustness of the science and any reviewers concerns before any decision for inclusion is made. The extensive scientific research required and international peer reviews required aid in the validation of the model outputs. Because the inventory model is based along the same lines as the tier 2 equations suggested in the IPCC guidelines, implied emission factors derived from the model outputs are easily comparable with other counties.

Documentation

All the equations and methodologies used within the Inventory model are documented so that calculations can be carried out external to the model if required. The document can be validated against the equations and code within the model itself, and the comparison of outputs from the external calculations and model calculations can also aid in the validation of results. Continual improvements in this area will aid in the ease of this validation.

Transparency

Although the calculations within the model can be complex due to the monthly time step, all equations, coding used, input and output worksheets can be accessed. For example the population model produces excel worksheets with monthly animal populations. These monthly populations are viewable for every year that the Inventory is calculated. Although predicted animal monthly populations can not be validated against actual statistical data, due to the transparency of these populations they can be easily reviewed to determine if they match expert opinion in this area. Recently such a review was carried out not only to check current model assumptions but to determine any changes in the industry since the model was developed. Although there has been some small movement within the industries for such things as birth date and slaughter dates, because the model uses actual activity data for the start and end populations in a year, these movements have had little over all affect on the monthly populations, highlighting the robustness of the current assumptions within the model.

As new research and improvements are incorporated into the model data management, transparency and documentation are improved. Initially inventory model input and output data was contained within excel spreadsheets. But as further years of emission are calculated, the move to regionalisation of dairy and improvements in the science, the amount of data needing to be managed is increasing. Therefore recently there has been substantial effort invested into developing an automated data management system which can easily and transparently store all required data. The ease of recalling data and checking data will be improved, and quality control checks will be automatically documented. This model will continue to use existing input and output data spreadsheets but these will automatically be populated from the data base. Outputs from the model will automatically be stored in the database. By keeping the spreadsheet and allowing them to be manually viewable the transparency of the calculations will not be compromised.

Integration with IPCC guideline methods

Both methane and nitrous oxide for the four main livestock species are derived from the tier 3 Inventory model. Implied methane emissions factors and nitrogen excretion rates for these species are calculated from these model results so that they can be integrated into IPCC default equations for comparison purposes. This information, along with tier 1 equations for other categories and minor livestock species are contained within tables in one final workbook for the final agricultural inventory compilation.

Along with improvements to data management for the inventory model, improvements to the final compilation process are also planned. Currently the compilation work book is a mixture of manual data input and automatic data input from the inventory model output worksheets. Once the data management system is finalised model outputs and data required for tier 1 calculations will automatically be retrieved from the database. Again access to tables and workbooks which carry out final calculations will still be achievable to ensure transparency of the process.

New Zealand’s Emissions Trading Scheme

In September 2008, New Zealand introduced an emissions trading scheme (ETS). The aim of the ETS is to spread the cost of emissions to New Zealand under its Kyoto Obligations to the polluter, The agricultural sector will be able to voluntarily report their emissions from 1 January 2011 and will be required to report from 1 January 2012. Because the ETS has been implemented to help New Zealand meeting its Kyoto obligations, it is important that the methodology used to estimate the cost to the industry aligns with the methodology used to calculate the National Inventory. The methodology for the ETS emission factor development is still currently in progress. However, a broad overview of the current draft methodology is detailed below.

Using the Inventory model

Inventory model outputs for livestock categories are annual emissions. These annual emissions for each livestock category were used to estimate lifetime emissions for animals captured by the ETS. For example the life time emissions for a slaughter bull of 2 years old were made up of the annual emissions from a slaughter bull 0 – 1 year, and emissions from a slaughter bull 1 – 2 yrs. Because of the extensive range of livestock categories modelled by the Inventory model, developing lifetime emission factors for all production animals was achievable. By changing the various production inputs into the Inventory model, lifetime emissions for animals with different production levels could also be determined.

In order to develop factors that could easily be used by the industry in the ETS, emission factors were developed based on information currently collected by the industry. For example, the industry already collects data on slaughter weight and slaughter animal number by stock class such as lamb. Therefore, a relationship between the slaughter weight and the lifetime emissions of slaughter animals was determined, a best fit linear trend line fitted and as this passed through the origin the slope was used to develop a per kg emission factor. As this best fit trend was determined using various production levels, it will not need to change as productivity levels change.

Because it is difficult to determine the age of a breeding animal at slaughter, their annual emissions of maintenance, gestation and lactation for each breeding year were allocated to the offspring as a per head emission factor. This is simply the annual emissions from a breeding cow, ewe or hind. Because it is difficult to relate this emission factor to the offspring itself, it is a weighted average of various “mother” weights for each species. This emission factor may therefore change if the “mother” average weight change. Each animal will therefore have a per kg and a per head emission factor associated with it at slaughter. The extra energy required each year by a milking cow is not incorporated into the per head emissions factor; rather it is allocated to the milk solid production of that year instead.

Comparing the Inventory with the ETS

Comparison of the emissions calculated using just the inventory model and the emissions calculated using the ETS emissions factors will not be identical. This is due to the differences in what each is measuring. The inventory calculates the emissions for a single year from all livestock alive during that year, while the ETS will measure the lifetime emissions of animals which are slaughtered in that year, and the annual emissions for milk production. Therefore in years were there may be above average slaughter of animals due to circumstances such as drought, the emissions estimated by the ETS will be higher than those estimated by the inventory.

Only national average emission factors for the ETS have currently been developed. However, because of the methodology already used in the inventory model and with the planned improvements, it may be possible to develop regional emission factors which take into account factors such as birth date, feed quality etc. Also, unique emission factors for circumstances different to the national average can be determined. This is achievable only because the inventory emissions are modelled. Various scenarios can be used as inputs into the inventory and population models and emission factors for the ETS can be determined for each scenario.

Verification

The ETS point of obligation for the agricultural sector is generally with the processor, with the exception of live animal exporters and egg producers who are also captured. This is mainly due to the requirement of verification of data. As already mentioned, processors in the agricultural industry already report slaughter weights and numbers of animals slaughtered. The dairy industry already reports milk solids processed. Therefore, verification of this data is simplified compared to individual farmers reporting their emissions. If the point of obligation was to move to the farmer level, systems would need to be developed so that verification of activity data could be achieved.

Over time, the ETS should create incentives for low emission research and technology. This could enable the ETS to be used as a source of verification and improvement of some activity data for the Inventory model inputs. For example, slaughter weights of various breeds and various animal categories. It can not used to validate the science behind the inventory model since the ETS uses the same science, but an increase in the collection of data motivated by the ETS may aid in other areas.

Estimation of national GHG emission from solid waste disposal sites by using field investigation results

*Komsilp Wangyao[1], *, Sirintornthep Towprayoon[1], Chart Chiemchaisri [2],*

Shabbir H. Gheewala[1], Annop Nopharatana[3]

Invited Background Paper to the IPCC Experts Meeting,

Sydney, Australia, 9 – 11 August 2010

[1] The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, Bangkok, Thailand 10140 E-mail: komsilp@jgsee.kmutt.ac.th, sirin@jgsee.kmutt.ac.th and Shabbir_g@jgsee.kmutt.ac.th

[2] Department of Environmental Engineering, Faculty of Engineering, Kasetsart University, Bangkok, Thailand 10900 E-mail: fengccc@ku.ac.th

[3] Pilot Plant Development and Training Institute, King Mongkut's University of Technology Thonburi, Bangkok, Thailand 10150 E-mail: annop@pdti.kmutt.ac.th

* *Corresponding author: komsilp@jgsee.kmutt.ac.th*

ABSTRACT

Measurements of landfill methane emission were performed at 9 solid waste disposal sites in Thailand including 5 managed sanitary landfills (4 deep and 1 shallow landfills), and 4 unmanaged landfill (3 deep and 1 shallow dumpsites). It was found that methane emissions during the rainy season were about 5 - 6 times higher than that during the winter and summer seasons in the case of managed landfill and 2-5 times higher in the case of unmanaged landfill. Comparison of methane emission estimate using the IPCC Waste Model to the actual field measurement from the studied disposal sites with methane correction factors and methane oxidation factors that obtained by error function analysis with default values of half-life parameters. The methane emissions from the first order decay model from the IPCC Waste Model yielded fair results compared to field measurements. The best fitting values of methane correction factor were 0.65, 0.20, 0.15 and 0.1 for deep landfill, shallow landfill, deep dumpsite and shallow dumpsite, respectively. Using these key parameters in case of Thailand, it was estimated that 89.22 Gg of methane were released from solid waste disposal sites into the atmosphere in 2006.

Keywords: landfill gas, methane emission, flux chamber, IPCC Waste Model, methane correction factor

INTRODUCTION

When municipal solid waste (MSW) is buried in a landfill, the biodegradable fractions that decompose via a complex series of microbial and abiotic reactions in anaerobic condition produce landfill gas (LFG) and leachate which amount to significant environmental emissions (Spokas et al., 2006). Most of the organic materials will be degraded over a longer or shorter period of time, ranging in a wide span from less than one year to 100 years or more. The majority of this process will be bio-degradation. Strongly depending on the conditions at the site where the waste is disposed, this biodegradation will be aerobic or anaerobic. The main degradation products are carbon dioxide (CO_2), water and heat for the aerobic process and methane (CH_4) and CO_2 for the anaerobic process. The CH_4 produced and released into the atmosphere contributes to global warming (Frøiland et al., 2002). Moreover, methane is a fairly potent greenhouse gas, with a global warming potential 21 times that of CO_2 (Foster et al., 2007). Landfills account for about 10-19% of annual global CH_4 emissions (Kumar et al., 2004). In 2005, worldwide solid waste disposal sites emitted 747.4 $MtCO_2eq$ (USEPA, 2006).

Recently, some models have been introduced to estimate the LFG generation rate of landfills. Among them, the first order decay (FOD) model is generally recognized as being the most widely used approach as it is recommended by the Intergovernmental Panel on Climate Change (IPCC, 2006) in the IPCC Waste Model and by the US Environmental Protection Agency (USEPA, 1998) in Landfill Gas Emission Model (LandGEM) for calculating methane emissions from landfills. Moreover, FOD model had been applied to other developed models such as Palos Verdes Model, Sheldon-Arleta Model, Scholl Canyon Model, First order model Netherlands (TNO), GasSim, European Pollutant Emission Register (EPER) model France (ADEME), EPER model Germany (Umwelt Bundesamt) (Cossu et al., 1996; Scharff and Jacobs, 2006). In the LandGEM, the model rests on two basic parameters, Lo, the methane generation potential (m^3 CH_4/Mg of MSW) and k, the methane generation rate constant (yr^{-1}), while the IPCC version rests on decomposable degradable organic carbon, DDOCm, instead of Lo (Sandro et al., 2009).

Thailand, one of the developing countries in Asia, experiences increasing urbanization, economic development and rapid growth of population. Problems arising from this development are municipal solid waste (MSW) management and disposal handling (Thailand Environment Monitor, 2003). Many cities and towns face serious environmental hazards and health risks. The country's MSW generation showed an increasing trend parallel to the development (Visvanathan et al., 2004). The increasing MSW generation along with the high fraction of organic waste and disposal by open dumping is the current scenario in many areas, which lack any precautionary environmental and health measures (Chiemchaisri et al., 2007). As response to this problem, recently, the country's Pollution Control Department (PCD) aims to replace open dumping with sanitary landfill, which reduces negative environmental impacts. However, the methane gas generation potential due to biological degradation of the organic waste fraction within anaerobic condition in sanitary landfills is higher than in open dumpsites because the former is more anaerobic due to the presence of a top barrier cover that provides favorable conditions for methane production (Chiemchaisri et al., 2007; IPCC, 2006). The design of all landfills in Thailand is based on the anaerobic landfill concept; thus, the main emissions in terms of gas will be of CH_4 and CO_2.

The total methane emissions from solid waste sector in Thailand were estimated at 76.51 Gg for the year 1990 by using mass balance method (TEI, 1996). In the year 1994, the total methane emissions were estimated at 19.57 Gg by the Office of Environmental Policy and Planning (OEPP) (OEPP, 2000). The estimation was obtained using a single phase model with theoretical first-order kinetics that takes into consideration the long period of release rather than the instantaneous emissions of methane. By using Landfill Air Emissions Estimation Model (LAEEM), the methane emissions were estimated at 24.77 Gg in 1994 and 92.26 Gg in 2000 (Towprayoon and Masniyon, 1999). This calculation was based on the single phase model and used country default values. Chiemchaisri et al. (2007) estimated methane emissions at 115.4 Gg in 2004 by using LandGEM which is based on the first-order decay reaction. By assuming that upgrading of open dumpsites to landfills will be complete in 15 years from 2005, it is estimated that the national methane emissions from those waste disposal sites will gradually increase to 339 Gg in 2020.

Presently, the IPCC Waste Model has been used in many countries as a standard tool for methane emission inventory from waste sector. However, the uncertainty of this model as well as the difference between estimates and real emissions from landfills have rarely been investigated or verified in Asian countries where most Clean Development Mechanism (CDM) projects are focused on. Measurements of methane emission from solid waste disposal sites are, therefore, important to reduce uncertainties in the inventory estimates from this source. The main objective of this study is to achieve an accurate estimation with IPCC Waste Model by optimizing methane correction factor and oxidation factor as well as also develop the country's default parameters for the emission inventory that can be applied to most developing countries-where the waste degrade under tropical condition.

METHODOLOGY

Site description

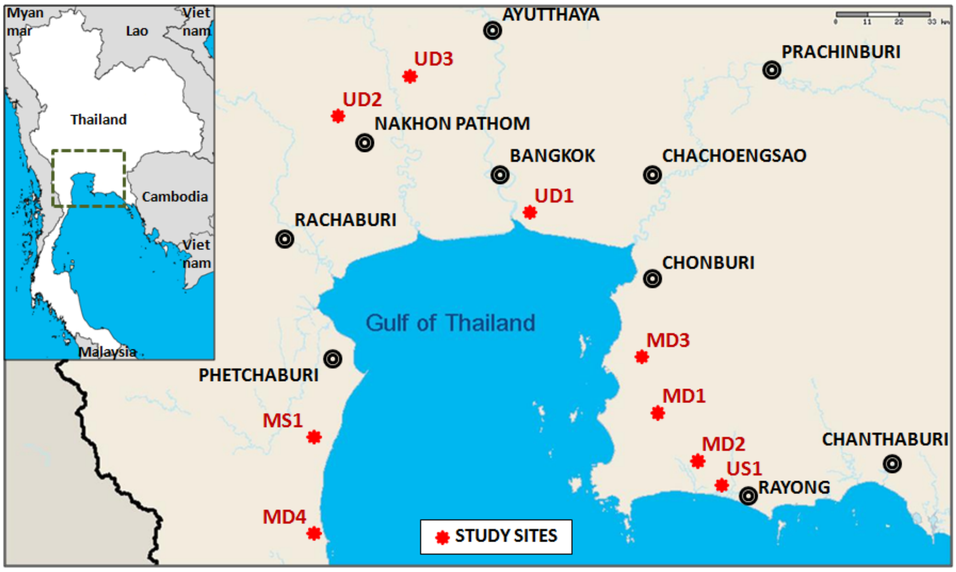


Figure 1 Location of study sites

Methane emission measurements were performed at 4 managed deep (MD) landfills (waste height ≥ 5m), 1 managed shallow (MS) landfill (waste height < 5m), 3 unmanaged deep (UD) landfills (deep dumpsites) (waste height ≥ 5m) and 1 unmanaged shallow(US) landfill (shallow dumpsite) (waste height < 5m), located in central Thailand. Landfill sites comprise of those at Pattaya (MD1), Mabtapud (MD2), Laemchabang (MD3), Hua-Hin (MD4) and Cha-Am (MS1). Deep dumpsites (waste height ≥ 5m) include those at Samut Prakan (UD1), Nakhon Pathom (UD2) and Nonthaburi (UD3) and a shallow dumpsite (waste height < 5m) locate at Rayong (US1). The location of study sites is shown in Figure 1. The characteristics of study sites are summarized in Table 1. The methane emission measurements were conducted from September to October 2005 for rainy season data, from December 2005 to February 2006 for winter season data and from April to May 2006 for summer season data. The characteristics of waste in these study sites that had been investigated by Pollution Control Department (PCD) of Thailand showed that food waste was the main component at all disposal sites ranging between 60% and 80%, followed by plastic, paper, glass, textile and wood (PCD, 2004). These composition can predict that significant of methane will generate at landfill site in the short time period because most of them are rapidly degradable waste combine with the appropriate moisture content and temperature under tropical condition in this region.

Methane emission rates and gas analysis

Methane emission rates from the landfill surface in this study were measured using the chamber technique which consists of trapping the gas as it leaves the soil surface, either by allowing the gas to build up in a closed enclosure (closed or static chamber technique) (Perera et al., 1999). Static chambers are the most frequently used technique for the measurement of gas fluxes from soils. The chamber technique is low cost, and simple to operate, but extremely labor and time intensive (Bogner et al., 1997). The chambers used in this study were constructed with ϕ 0.40 m PVC pipe (covering an area of 0.126 m^2), 0.25 m. in height and with a PVC cap at the top of the chamber. To protect against air intrusion, the chambers were sealed to the ground by placing wet soil around the outside. Methane samples were collected in 10-mL vacuum tubes from a chamber after 1, 2, 3, and 4 minutes using 60-mL plastic syringes fitted with plastic valves. The samples were analyzed using a gas chromatograph equipped with a flame ionization detector (GC-FID). The methane flux was determined from concentration data (C in ppmv) plotted versus elapsed time (t in minutes). The data generally fit a linear relationship, in which case dC/dt is the slope of the fitted line. The methane flux, F ($g/m^2/d$), was then calculated as follows in Equation 1 (Rolston, 1986; Hegde et al., 2003):

$$F = \frac{V}{A}\left(\frac{dC}{dt}\right) \qquad (1)$$

Where V is chamber volume and A is the area covered by the chamber. The slope of the line, dC/dt, was determined by the differential result between CH_4 concentration and elapsed time.

In order to conduct the flux chamber measurements, numerous samples were collected across the landfill or dumpsite surfaces on a regular grid pattern at 30 – 40m intervals. Precipitation was absent and barometric pressure and ambient wind speed, factors which known to affect emissions, were relatively constant during investigations.

Geospatial distribution

Due to the large areal extent of landfill surfaces and the heterogeneous nature of landfill gas fluxes, a large number of chamber samples must be collected (Mosher et al., 1999). However, proper interpolation methodology must be applied for geospatial analysis of field data. This technique offers the potential of calculating whole site emission estimates from point measurements, which could lead to improving the estimation of landfill methane emission (Spokas et al., 2003). Geospatial distributions of the methane emissions in this study were estimated by Kriging method. Kriging refers to the process of using the spatial dependency to predict the value of a property at unknown locations from the relationship observed at the sampling location. The weight for the Kriging analysis was decided by semivariogram (Spokas et al., 2003). The Surfer software (Golden Software, Inc.) was used to analyze the geospatial distribution in this study. The Kriging model was applied to map the results, and the volumetric value of the contour map was estimated by volume and area integration algorithms in Surfer.

Table 1 Characteristics of study sites

Site	Landfill Open Year	Site Age from 2006 (yrs)	Area (m^2)	Disposal method	Average tipping (tonnes per day)
Pattaya (MD1)	2002	4	53,618	Deep landfill	240
Mabtapud (MD2)	2001	5	29,280	Deep landfill	58
Cha-Am (MS1)	2000	6	47,680	Shallow landfill	26
Laemchabang (MD3)	1999	7	71,200	Deep landfill	152
Hua-Hin (MD4)	1996	10	44,160	Deep landfill	46
Samut Prakan (UD1)	1999	7	25,600	Deep dumpsite	80
Nakhon Pathom (UD2)	1997	9	48,781	Deep dumpsite	180
Nonthaburi (UD3)	1982	24	67,367	Deep dumpsite	800
Rayong (US1)	2001	5	35,200	Shallow dumpsite	69

Methane emission inventory

In order to compare methane emissions between field investigations and model estimation, the IPCC Waste Model was used in this study. In the model, CH_4 emissions from landfills for a single year are estimated using the following equation;

$$CH_4 Emissions = \left[\sum_x CH_4 generated_{x,T} - R_T \right] \times (1 - OX_T) \quad (2)$$

Where CH_4 *Emissions* = CH_4 emitted in year *T*, Gg, *T* = inventory year, *x* = waste category or type/material, R_T = recovered CH_4 in year *T*, Gg, and OX_T = oxidation factor in year *T*, (fraction). The OX reflects the amount of CH_4 from solid waste disposal site (SWDS) that is oxidized in the soil or other material covering the waste. The amount CH_4 generated from decomposable material in year *T* (=CH_4 $generated_T$) is estimated using the first order decay (FOD) of the mass of decomposable organic carbon (= *DDOCm*, Gg) in each waste category or type/material as follows;

$$CH_4\ generated_T = DDOCm\ decomp_T \times F \times 16/12 \quad (3)$$

Where $DDOCm\ decomp_T$ = *DDOCm* decomposed in year *T*, Gg, *F* = fraction of CH_4 by volume in generated landfill gas (fraction) and 16/12 = molecular weight ratio between methane and carbon (ratio).

$$DDOCm\ decomp_T = DDOCma_{T-1} \times \left(1 - e^{-k}\right) \quad (4)$$

$$DDOCma_T = DDOCmd_T + \left(DDOCma_{T-1} \times e^{-k}\right) \quad (5)$$

Where $DDOCma_T$ = *DDOCm* accumulated in the solid waste disposal site at the end of year *T*, Gg, $DDOCma_{T-1}$ = *DDOCm* accumulated in the SWDS at the end of year *T*-1, Gg, $DDOCmd_T$ = *DDOCm* deposited into the SWDS in year *T*, Gg, *k* = reaction constant ($k = \ln(2)/t_{1/2}$), yr^{-1}, and $t_{1/2}$ = half-life time, yr.

$$DDOCm = W \times DOC \times DOC_f \times MCF \quad (6)$$

Where *W* = mass of waste deposited, Gg, *DOC* = degradable organic carbon in the year of deposition, (fraction, Gg-C/Gg-waste), DOC_f = fraction of *DOC* that can decompose, (fraction), and *MCF* = CH_4 correction factor for aerobic decomposition in the year of deposition, (fraction).

Parameter evaluation

The emission results that were obtained from field investigations have been modeled with the FOD model (IPCC Waste Model). To find the optimal set of gas generation parameters, the approach by Oonk et al. (1994) was used. This entails the minimization of the difference between the calculated gas generation rates and the actual rates to determine the optimal set of gas generation parameters using error function for statistical analysis. The error equation used is shown as Equation 7.

$$E = \sqrt{\sum_{i=1}^{n} (Qc - Qob)^2} \quad (7)$$

Where *E* is error function, *Qc* is calculated generation, *Qob* is observed generation and *n* = number of waste disposal sites.

By following this approach, MCF, the main parameter, was first optimized. The MCF is the fraction of waste which degrades anaerobically in landfills. The value of this parameter depends on the landfill operation, shape or the specific surface of landfills, the existence and the air permeability of the top cover, the water content or the level of leachate in landfills. In the IPCC Guidelines, default value for the MCF is classified in four categories for simplification. In this study, MCF was evaluated by using error function analysis with IPCC Waste Model and information of study sites including waste composition, waste in place history, and operation practice. In order to optimize MCF, other parameters were fixed with IPCC default values for tropical climate region except oxidation factor (OX). The default half-life values for food waste, paper, wood and textiles were 2, 10, 20 and 10 years, respectively. The default delay time was 6 months. The value of oxidation factor for landfill was fixed at 0.15 following Chomsurin (1997). However, OX of dumpsite had been evaluated by error function analysis.

RESULTS

Methane emissions from field investigation

In this experiment, concerning the fluctuation of weather in tropical country during year round, we measured methane emissions from 9 disposal sites in Thailand during wet and dry seasons. There are three seasons in Thailand according to weather data and amount of rainfall namely, rainy, winter and summer seasons. Weather data from Thai Meteorological Department showed that the average atmospheric temperature during emission measurement in the rainy, winter and summer seasons were 28.5, 26.5 and 29.2 ^{o}C, respectively. However, the monthly precipitation rate had significant differences that were 258.4, 30.5 and 134.6 mm./month in the rainy, winter and summer seasons, respectively. The surface methane emission results are summarized in Table 2. These results indicated that high spatial heterogeneity of methane emission (high standard deviation) can be found in all study sites especially in wet season. The phasing of waste tipping was the main reason of the high spatial heterogeneity at all disposal sites that waste was degraded under different degradation stage. In this study, most of high methane emissions were found at the younger phase compared to older phase that gave low CH_4 emissions. From Figure 2, It can be seen that manage landfill showed high methane emission than unmanaged landfill for the whole season. In addition, methane emissions of manage landfill during the wet season (rainy season) were about 5 - 6 times higher than dry season (winter and summer seasons) whereas it was only 2 - 5 times in unmanaged landfills. Although methane emission during winter and summer were low, theirs values were in close proximity in the managed landfill and were two times different in the unmanaged landfill. Moisture content in the waste body might be the most important parameter in the waste degradation. In the wet season, moisture content in the waste body will be increased by intrusion of rain passing through daily cover. The additional moisture stimulates microbial activity by providing better contact between insoluble substrates, soluble nutrients and microorganisms. These phenomena enhance decomposition and generate more LFG (Barlaz et al., 1990).

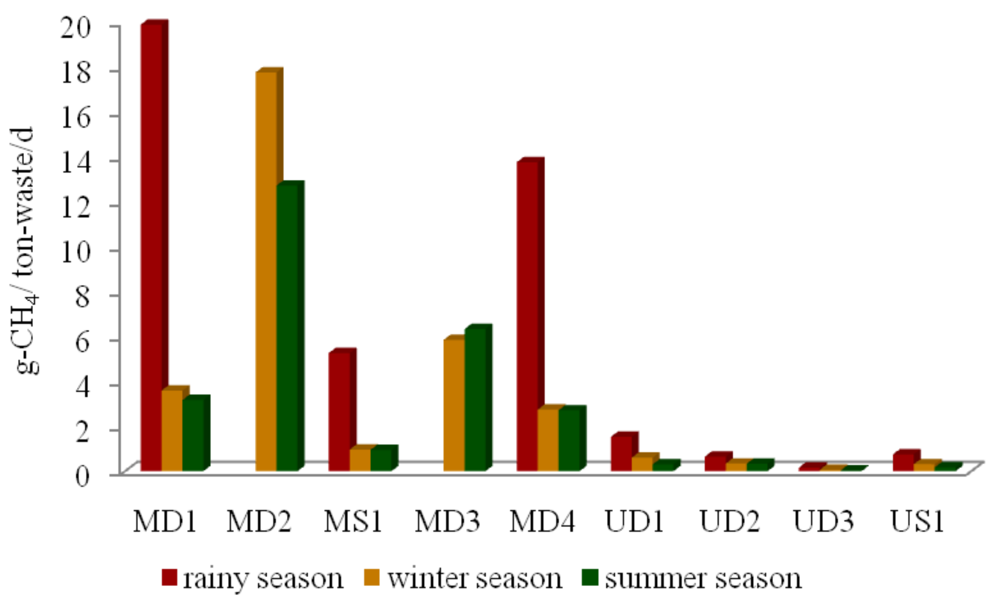


Figure 2 Emission of methane per ton of waste in place per day from the different landfill sites during rainy, winter and summer season

As anticipated, the average spatial methane emissions from unmanaged landfill were substantially lower than from managed landfills in all seasons. Moreover, the average spatial methane emissions in shallow landfill were lower than deep landfills. This may have resulted from the intrusion of air into the landfill which might decrease anaerobic waste degradation. The waste is stabilized rapidly through aerobic condition that has an additional benefit of reducing landfill emissions of methane (Peck et al., 2007). The waste degradation phenomenon in shallow landfill seems as if it was degraded under semi-aerobic condition. However, the total methane emissions per unit waste in place (WIP) or emission factor for managed shallow landfills was significantly lower than that for managed deep landfills as shown in Table 2.

Methane estimation from IPCC Waste Model

The results from error function analysis showed that the best fitting values of MCF which gave low error function value were 0.65, 0.20, 0.15 and 0.10 for deep landfill, shallow landfill, deep dumpsite and shallow dumpsite, respectively when OX values were justified to 0.15 and 0.70 for managed landfill and unmanaged landfill, respectively as shown in Figure 3 and 4.

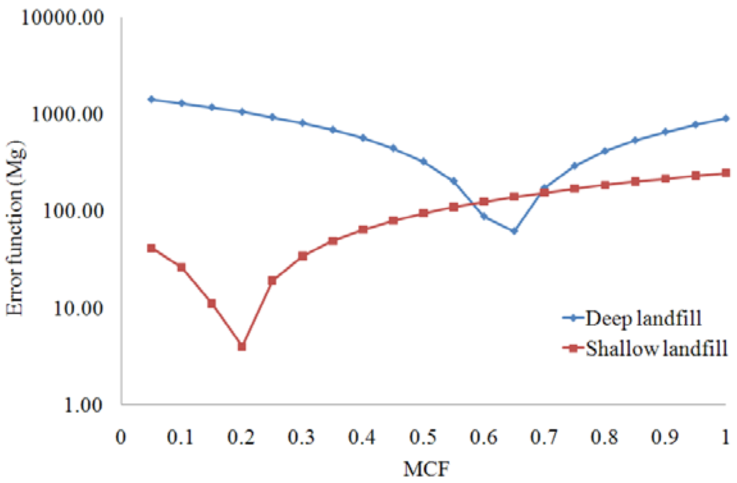


Figure 3 Error function analysis of MCF for managed landfill

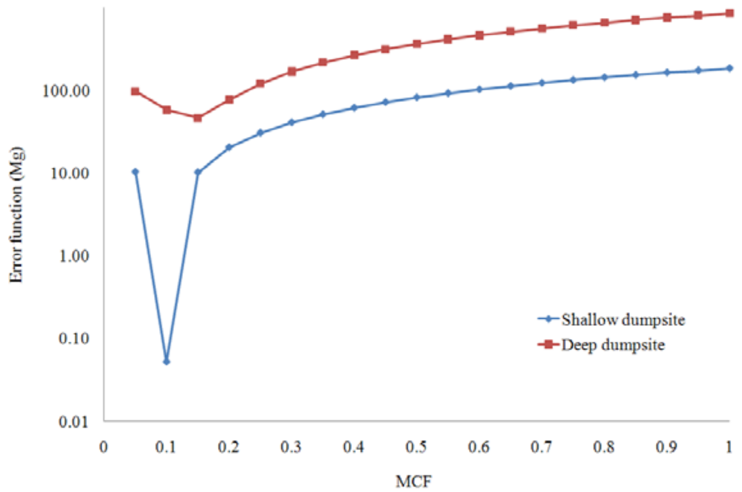


Figure 4 Error function analysis of MCF for unmanaged landfill

The MCF values obtained are thus lower than the IPCC default values. In contrast, OX values are higher than the IPCC default values. As the air permeability of the cover soil in landfills and dumpsites corresponds with poor daily cover operation in case of landfill that some parts of waste degraded under aerobic condition, the MCF and OX were different from IPCC default values.

Comparison of model parameters with field investigations

The parameters that were obtained from error function analysis and information from each study site based on information at each site including waste composition, waste in place, history and operation practice were used to calculate methane emissions in the IPCC Waste Model again. Total methane emissions were calculated by summarizing seasonal emissions that was calculated by multiplying daily methane emission in each season with the period of the season. The calculation results and field measurements of methane emissions at all sites are summarized in Table 3.

The comparison results show that the methane emissions from the IPCC Waste Model gave fair results compared to field measurements in both cases of managed and unmanaged landfills as seen in Figure 5 with the R^2 of 0.65. The differences between calculations and field measurements at the MD1, MD2, MD4 and MS1 were -2.53%, 16.50%, -11.08% and -7.11%, respectively. At MD3, the calculated value was about 65.51% lower than field measurement. This big difference may be caused by the uncertainty of waste loaded to the site dealing with MSW and other non-hazardous waste from industry while the input parameter used in IPCC Waste Model was only MSW composition because of the lack of non-hazardous waste compositions data.

However, the calculations of methane emission from dumpsite were close to field investigations in the cases of US and UD2 revealed by a very low error. At UD3 and UD1, errors of estimation amount to about 50%. These errors may be caused by incorrect data of waste quantity because some parts of waste were moved to other landfills in the case of UD3. At UD1, the quantity of waste was estimated by base on waste delivery vehicle capacity, uncertainty is higher and may effects to emission inventory.

Table 3 Comparison of methane emissions in 2006 (Mg) from FOD model and field measurements

Site	Operation practice	Default MCF	Selected MCF	Default OX	Selected OX	IPCC Waste Model	Field measurement	Diff.
MD1	Managed – deep (Active)	1.00	0.65	0.10	0.15	1,523.30	1,485.75	-2.53%
MD2	Managed - deep (Active)	1.00	0.65	0.10	0.15	127.76	153.01	16.50%
MD3	Managed - deep (Active)	1.00	0.65	0.10	0.15	715.62	2,074.87	65.51%
MD4	Managed - deep (Active)	1.00	0.65	0.10	0.15	420.11	378.21	-11.08%
MS1	Managed – shallow (Active)	1.00	0.2	0.10	0.15	60.07	56.08	-7.11%
UD1	unmanaged - deep (Active)	0.80	0.15	0.10	0.70	42.45	73.89	42.55%
UD2	unmanaged - deep (Active)	0.80	0.15	0.10	0.70	106.12	106.52	0.37%
UD3	unmanaged - deep (Inactive)	0.80	0.15	0.10	0.70	97.67	63.26	-54.39%
US1	unmanaged - shallow (Active)	0.40	0.1	0.10	0.70	20.60	20.65	0.25%

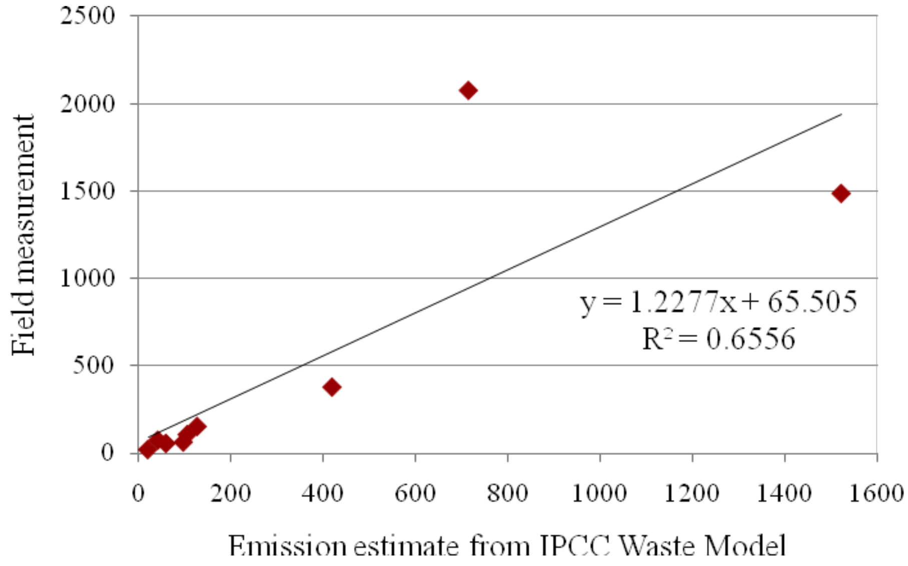


Figure 5 Relation of estimate methane emission and field measurement (Mg)

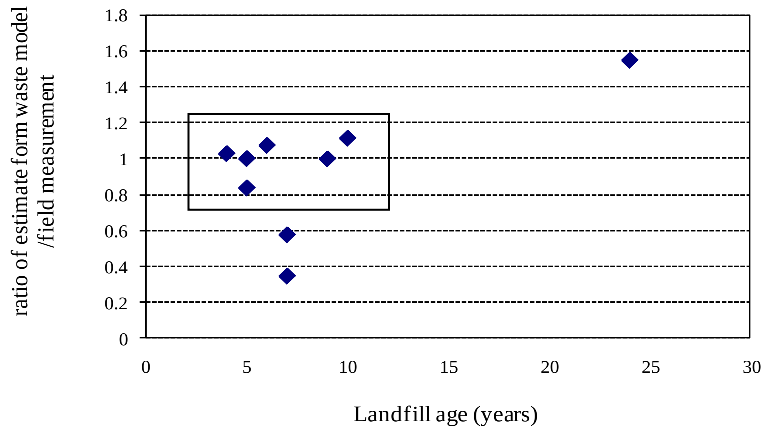


Figure 6 Ratio of methane emission from waste model versus field measurement

The ratio of estimate emission from IPCC Waste Model to field measurement is showed in Figure 6. In general, most of the ratios are between 0.8-1.1. There are three points that are departing from the others, MD3, UD3 and UD1. Ratio of MD3 is 0.3 which may due to the reason explained above. UD3 (ratio 1.5) is a 24 years old unmanaged deep which poor operation system that lead to difficultly during measurement. The site at UD1 with the fair ratio of 0.6 is also unmanaged deep landfill. Despite the site at MD3, calculation of methane emission using IPCC Waste Model with the local value of MCF, OX and site specific waste composition has shown the good relationship. The MCF, half-life time, OX and delay time that were obtained from this study can be used as country-specific parameters in the FOD model that will be used for landfill methane emission inventory in the subsequent section following the Tier 2 methodology of the IPCC.

Figure 7 illustrated the application of waste model in managed landfills and unmanaged landfills in relation to landfill age and the quantity of waste in place. It is observed that emissions from managed landfill either by IPCC Waste Model and field measure show lower emission in different age at the close proximity value and corresponded to their waste in place except MD3 where specific composition of waste in place per day is uncertain. The results from unmanaged landfill sites follow the same pattern of managed landfill except for UD3 where low emission is observed despite the large amount of waste in place per day. This may be due to the long life time of this landfill and the improper operation of this specific site. However, it is note that the MCF used in managed landfill sites here is 0.65 which is lower than that recommendation from IPCC 2000 Good Practice Guidance and that OX of 0.15 is applied due to local experiment and conditions

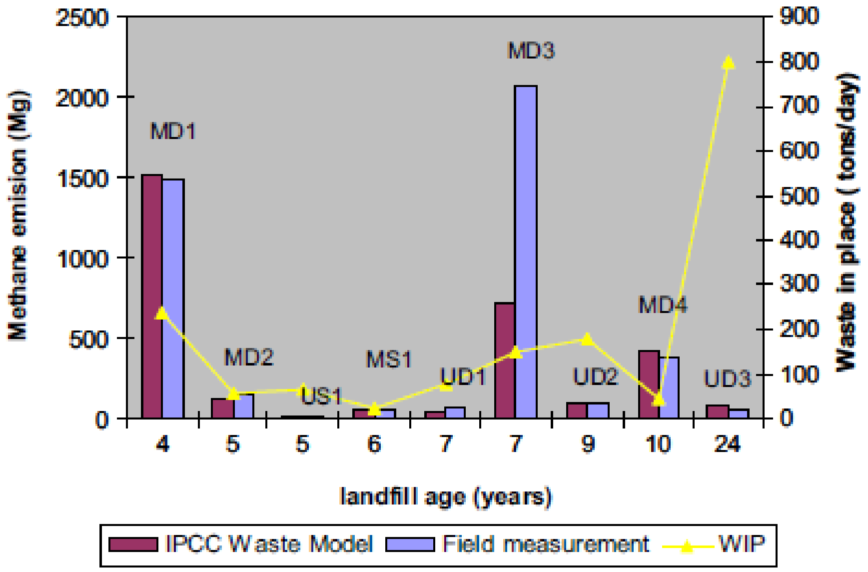


Figure 7 Relation of methane emission from waste model and field measure to landfill age and waste in place (data in year 2006)

Table 2 Summary of methane emission from study sites

		rainy season				winter season				summer season			
Site	waste in place, WIP (Until the end of 2005)	range ($g/m^2/d$)	mean and S.D. ($g/m^2/d$)	avg. spatial CH_4 emissions ($g/m^2/d$)	total CH_4 emissions/ WIP (g-CH_4/ ton-waste/d)	range ($g/m^2/d$)	mean and S.D. ($g/m^2/d$)	avg. spatial CH_4 emissions ($g/m^2/d$)	total CH_4 emissions/ WIP (g-CH_4/ ton-waste/d)	range ($g/m^2/d$)	mean and S.D. ($g/m^2/d$)	avg. spatial CH_4 emissions ($g/m^2/d$)	total CH_4 emissions/ WIP (g-CH_4/ ton-waste/d)
MD1	349,856	0.38 - 719.35	135.33 and 191.65	129.79	19.89	N.D. - 686.93	24.51 and 106.80	23.40	3.59	0.21 - 167.00	17.90 and 30.24	20.69	3.17
MD2	89,134	not measured				N.D. - 677.77	54.00 and 126.79	54.06	17.76	0.63 - 318.81	40.64 and 68.26	38.71	12.72
MS1	49,442	N.D. - 58.34	7.43 and 15.83	5.45	5.26	N.D. - 8.45	1.26 and 2.24	1.00	0.96	0.01 - 10.70	1.25 and 2.33	0.99	0.95
MD3	279,887	not measured				N.D. - 638.61	44.95 And 112.67	22.99	5.85	0.10 - 428.51	26.00 and 73.39	24.90	6.33
MD4	166,101	N.D. - 295.82	50.20 and 71.89	51.76	13.76	N.D. - 117.00	10.18 and 19.91	10.31	2.74	0.07 - 211.36	10.14 and 32.50	10.18	2.71
UD1	204,400	N.D. - 60.00	14.59 and 18.77	12.21	1.53	0.93 - 14.28	5.07 and 4.63	4.82	0.60	0.58 - 9.06	3.22 and 2.95	2.39	0.30
UD2	591,300	N.D. - 825.79	43.16 and 154.36	7.89	0.65	N.D. - 38.09	4.89 and 9.38	4.17	0.34	0.14 - 28.95	4.05 and 7.01	3.98	0.33
UD3	1,700,000	N.D. - 69.11	6.14 and 15.80	3.94	0.16	N.D. - 19.94	1.81 and 4.33	1.64	0.06	0.04 - 3.64	0.71 and 0.82	0.77	0.03
US1	113,960	N.D. - 22.79	2.59 and 5.30	2.44	0.75	0.06 - 2.89	0.99 and 0.85	1.00	0.31	0.06 - 1.51	0.53 and 0.52	0.55	0.17

.Methane emission inventory from solid waste sector in Thailand using IPCC Waste Model

During the past decade, the waste generation in Thailand increased from 12.6 million tons in 1995 to 14.6 million tons in 2004 (PCD, 2005). However, most of the wastes were disposed via open dumping and open burning. Only 91 out of 1,145 city districts had sanitized disposal management. In 2004, it has been estimated that 36% of waste generated was disposed in landfills. In this study, the assessment of methane emissions in the solid waste sector of Thailand from 1981 - 2006 has been carried out by using IPCC Waste Model with available waste historical and waste composition data at each landfill site as well as MCF and OX that obtained from error function analysis. The parameters of DOC, DOCf, and fraction to methane used the IPCC default values. The DOC of food waste, papers, wood and textiles were 0.15, 0.4, 0.43 and 0.24, respectively, DOCf was 0.5. The k value for each type of waste that was compiled by half-life values and delay time was obtained results from field investigations and model calibration as described previously. The k values for food waste, papers, wood and textiles were 0.347, 0.069, 0.035 and 0.069 yr^{-1}, respectively. The delay time was 6 months. The CH_4 fraction of generated LFG, F, was taken to be 0.5. Information including site characteristics, waste receiving rate and waste characteristics obtained from the PCD that were studied from 1993 to 2005 were used in IPCC Waste Model. The methane emission calculation in each site was separately evaluated.

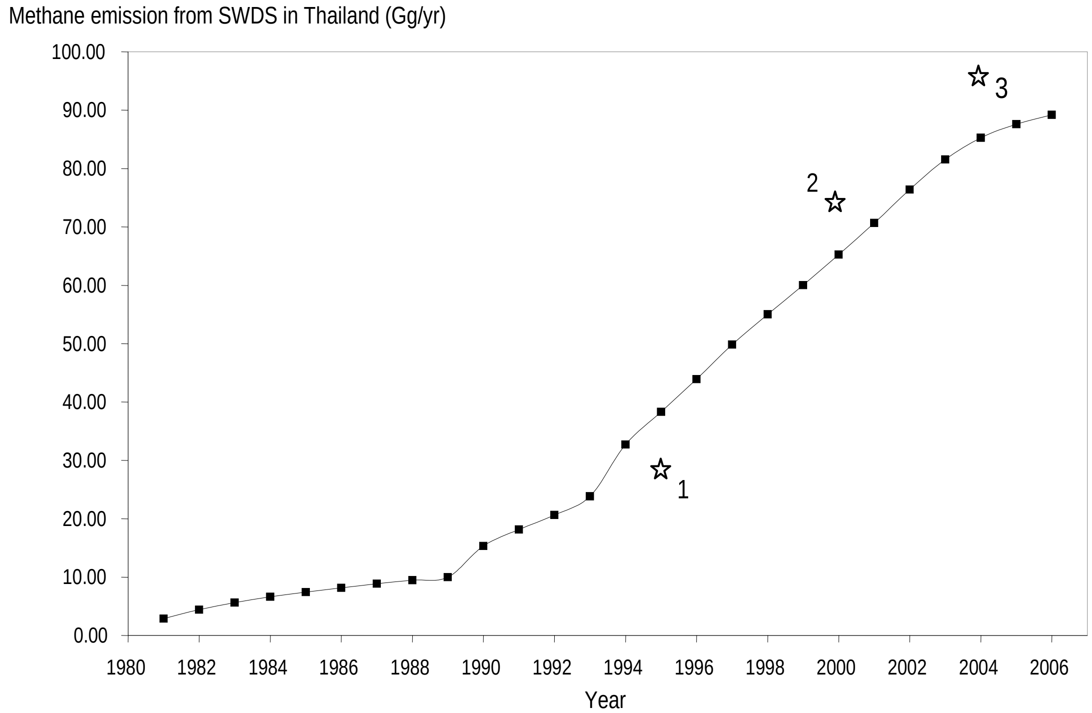


Figure 8 The trend of methane emissions from solid waste disposal sites in Thailand

Notes: *1* 1994 emission estimated by Towprayoon and Masniyom using the Landfill Air Emissions Estimation Model (LAEEM).
2 2000 emission estimated by Towprayoon and Masniyom using LAEEM.
3 2004 emission estimated by Chiemchaisri et al. using Land GEM.

The results of calculations of methane emissions from 1981-2006 are presented in Figure 8. From 1981 to 1992, the methane emission increased at the rate of about 1.6 Gg/year. Landfill practices were implemented only in big cities. After 1993, PCD promoted landfill as a good practice for waste disposal technique for the country. The methane emission increased by about 5 Gg/year. The results of the methane emission inventory show that 89.22 Gg/year of methane were released from solid waste disposal sites into the atmosphere in 2006. The majority of these emissions were from food waste, which contributed about 50 percent of the total waste emissions.

CONCLUSION

This paper presents field data of methane emission from different type of solid waste disposal sites in central Thailand and compared their emissions to IPCC waste model estimation. Results from field measurement illustrated that rainy season showed influential effect to methane emission in both managed landfill (5-6 times higher than other seasons) and unmanaged landfill (2-5 times higher). Application of IPCC Waste Model to the studied sites showed that, by using error function analysis, the best fitting values of MCF were 0.65, 0.20, 0.15 and 0.10 for deep landfill, shallow landfill, deep dumpsite and shallow dumpsite, respectively. OX values used in this study were 0.15 and 0.70 for landfill and open dumpsite, respectively. The half-life values for food waste, paper, wood and textiles that were obtained from this study were 2, 10, 20 and 10 yr^{-1}, respectively. The delay time was 6 months. Estimation of methane emissions from the IPCC Waste Model with the above parameter gave fair results compared to field measurement in many different cases including type of landfill, age and waste in place. However, sites with specific operation and uncertain operation resulted in departed value from the field measurement.

The key parameters including the MCF, OX, half-life and delay time that were obtained from this study can be used as country-specific parameters for Thailand and other countries in South East Asian region with similar circumstances in the application of IPCC Waste Model. Using these country-specific values, as the Tier 2 methodology, also helps to reduce uncertainties as well as improve the quality of estimation. On the other words, the obtained MCF values also mean to the improper landfill operation in developing countries that will reduce the methane generation potential compare to the well operated landfill in developed countries. In order to estimate the size (capacity) of landfill gas recovery plant or evaluate the emission reduction in the CDM for tropical developing countries, the methane generation potential should be reduced with the obtained MCF as the reduction factor.

REFERENCES

Barlaz, M., Ham, R., Schaefer, D. (1990) Methane production from municipal refuse: a review of enhancement techniques and microbial dynamic. Critical reviews in Environmental Control, 19, 557-584.

Bogner, J., Meadows, M. & Czepiel, P. (1997) Fluxes of methane between landfills and the atmosphere: natural and engineered controls. Soil Use and Management, 13, 268-277.

Chiemchaisri, C., Juanga, J.P., Visvanathan, C. (2007) Municipal solid waste management in Thailand and disposal emission inventory. Environmental Monitoring and Assessment, 135, 13-20.

Chomsurin, C. (1997) Evaluation of Gas Migration and Methane Oxidation in Domestic Solid Waste Landfill, Master's Thesis, Asian Institute of Technology.

Cossu, R., Andreottola, G., Muntoni, A. (1996) Modelling landfilling gas production. In: T.H. Christensen, R. Cossu and R. Stegmann, Editors, Landfilling of Waste: Biogas, E&FN Spon Publisher, 237–268.

Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz, R. Van Dorland (2007) Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Frøiland Jensen, J. E., Pipatti, R. (2002) CH_4 Emissions from Solid Waste Disposal. In: IPCC, 2002. Background Papers. IPCC Expert Meetings on Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, IPCC-NGGIP, IGES, Hayama, Japan, 419-465.

Hegde, U., Chang, T.C., Yang, S.S. (2003) Methane and carbon dioxide emissions from Shan-Chu-Ku landfill site in northern Taiwan, Chemosphere, 52, 1275-1285.

IPCC (2006) IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

Kumar, S., Gaikwad, S.A., Shekdar, A.V., Kshirsagar, P.S., Singh, R.N. (2004) Estimation method for national methane emission from solid waste landfills, Atmosphere Environment, 38, 3481-3487.

Mosher, B. W., Czepiel, P. M., Harriss, R. C., Shorter, J. H., Kolb, C. E., McManus, J. B., Allwine, E., Lamb, B. K. (1999) Methane Emissions at Nine Landfill Sites in the Northeastern United States, Environmental Science & Technology, 33, 2088 -2094.

Office of Environmental Policy and Planning (OEPP). (2000) Thailand's National Greenhouse Gas Inventory 1994. Ministry of Science, Technology and Environment. Bangkok, Thailand. 118 p.

Oonk, J., Weenk, A., Coops, O., Luning, L. (1994) Validation of Landfill Gas Formation Models, Institute of Environment and Energy Technology, Report No. 94-315.

Peck, J., Bentley, H., Hudgins, M. (2007) Basic to support the development of a new methodology to determine a voided greenhouse gas emissions from in situ aerobic stabilization of landfills. Proceedings Sardinia 2007, Eleventh International Waste Management and Landfill Symposium, S. Margherita di Pula, Cagliari, Italy; 1-5 October 2007.

Perera, M.D.N., Hettiaratchi, J.P.A., Achari, G. (1999) A mathematical model to improve the accuracy of gas emission measurements from landfills. Proceedings Sardinia 99, Seventh International Waste Management and Landfill Symposium S. Margherita di Pula, Cagliari, Italy; 4-8 October 1999.

Pollution Control Department (PCD) (2004) Surveying and Evaluation of Physical Compositions of MSW. Ministry of Natural Resources and Environment, Bangkok (in Thai).

Pollution Control Department (PCD) (2005) Report on Thailand State of Pollution. Ministry of Natural Resources and Environment, Bangkok

Rolston, D.E. (1986) Gas flux. In: Klute, A. (Ed.), Methods of soil analysis, second ed. American Society Agronomy and Soil Science Society, American Monograph No. 9, Wisconsin, USA, 1103-1119.

Sandro L. Machado, Miriam F. Carvalho, Jean-Pierre Gourc, Orencio M. Vilar, Julio C.F. do Nascimento (2009) Methane generation in tropical landfills: Simplified methods and field results, Waste Management, 29, 153-161.

Scharff, H., Jacobs, J. (2006) Applying guidance for methane emission estimation for landfills, Waste Management, 26, 417-429.

Spokas, K., Graff, C., Morcet, M., Aran, C. (2003) Implications of the spatial variability of landfill emission rates on geospatial analyses. Waste Management, 23, 599–607.

Spokas, K., Bogner, J., Chanton, J.P., Morcet, M., Aran, C., Graff, C., Golvan, Y.M., Hebe, I. (2006) Methane mass balance at three landfill sites: What is the efficiency of capture by gas collection system? Waste Management, 26, 516-525.

Thailand Environment Institute (TEI) (1996) Annual Conference "Linking Local Solution to Global Needs: Thailand's Environment Agenda in the 21 Century" Climate Change-Local Solution for global Problems.

Thailand Environment Monitor (2003) A joint publication of the Pollution Control Department (PCD) of Thailand's Ministry of Natural Resources and Environment (MoNRE), the World Bank, the United States-Asia Environmental Partnership (USAEP), and Japan Bank for International Cooperation (JBIC). Retrieved June 30, 2006 from http://www.worldbank.or.th/WBSITE/EXTERNAL/COUNTRIES/EASTASIAPACIFICEXT/THAILANDEXTN/0,,contentMDK:20206649~menuPK:333323~pagePK:141137~piPK:217854~theSitePK:333296,00.html.

Towprayoon, S., Masniyon, M. (1999) Calculation of Methane Emission from Landfill Using Country Default Value. Proceeding of Inter-Regional Symposium on Sustainable Development (ISSD) 18-20 May, Kanchanaburi, Thailand.

USEPA (1998) Landfill Air Emissions Estimation Model (Version 2.01), EPA-68-D10117, EPA 68-D3-0033, US Environmental Protection Agency.

USEPA (2006) Global Anthropogenic Non-CO2 Greenhouse Gas Emissions: 1900-2020, EPA Report 430-R-06-003.

Visvanathan, C., Trankler, J., Joseph, K., Chiemchaisri, C., Basnayake, B.F.A., Gongming, Z. (2004) Municipal solid waste management in Asia. Asian Regional Research Program on Environmental Technology (ARRPET). Asian Institute of Technology publications. ISBN: 974-417-258-1.

Comparison of the UK inventory and other EU inventories with the EU Emission Trading System combustion CO_2 data

Neil Passant, Glen Thistlethwaite, Joanna MacCarthy, and John Watterson

With contributions from Sarah Choudrie

AEA Technology, UK

Invited Background Paper to the IPCC Experts Meeting,

Sydney, Australia, 9 – 11 August 2010

1 Introduction

This report is the background paper to accompany the presentation on the comparison of the UK inventory and other EU inventories with the EUETS combustion CO_2 data.

The paper is split into 2 parts: an analysis of the EUETS data used in the UK inventory and the limitations ands lessons learned from this, and then followed by general comments on the use of ETS data in the EU inventory, including a more detailed analysis of ETS data use in selected countries in the EU inventory. It presents some questions for discussion about the ways to make best use of ETS data in GHG inventories.

1.1 The EUETS

The EU 2010 National Inventory Report (NIR)[8] provides a good summary of the implementation and operation of the EUETS. The text below is taken from that report.

1.1.1 Description

In January 2005 the European Union Greenhouse Gas Emission Trading System (EUETS) commenced operation as the largest multi-country, multi-sector Greenhouse Gas Emission Trading System world-wide. The scheme is based on Directive 2003/87/EC, which entered into force on 25 October 2003. The European emissions trading system (ETS) covers around 10,500 installations across the 27 Member States of the European Union.

The EUETS operates by the allocation and trading of greenhouse gas emissions allowances throughout the EU; one allowance represents one tonne of carbon dioxide equivalent. An overall limit, or 'cap', is set by Member State's Governments on the total amount of emissions allowed from all the installations covered by the scheme. The allowances are then distributed to the installations in the scheme. At the end of each year, operators are required to ensure they have enough allowances to cover their installation's emissions. They have the flexibility to buy additional allowances (on top of their free allocation), or to sell any surplus allowances generated from reducing their emissions. These options create a flexible compliance regime for operators and also ensures emissions are effectively capped across the EU.

Installations covered by the EU ETS are those which carry out activities listed in Annex I of the EU ETS Directive. These include energy activities, production and processing of ferrous metals, mineral industries and pulp and paper industries.

The scheme currently has two operating phases:

- Phase 1 from 1 January 2005 to 31 December 2007
- Phase 2 from 1 January 2008 to 31 December 2012

1.1.2 Monitoring, Reporting and Verification

Article 14 of the Emission Trading (ET) Directive requires Member States to ensure that emissions are monitored in accordance with specific monitoring and reporting guidelines (MRG)[9], which are legally binding. Since 1 January 2005, all installations covered by the ETS have been required to estimate and report their emissions. Data for the installations covered by the ETS are reported by plant operators to competent authorities since 2005 based on a monitoring plan elaborated by the company and agreed by the competent authority in accordance with the methodologies established in the monitoring and reporting guidelines. The monitoring plan covers the following elements:

a) the description of the installation and activities carried out by the installation to be monitored;

b) information on responsibilities for monitoring and reporting within the installation;

c) a list of emissions sources and source streams to be monitored for each activity carried out within the installation;

d) a description of the calculation based methodology or measurement based methodology to be used;

8 http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/5270.php

9 Commission Decision 2007/589/EC of 18 July 2007 establishing guidelines for the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council. OJ L 229, 31.8.2007, p.1ff

e) a list and description of the tiers for activity data, emission factors, oxidation and conversion factors for each of the source streams to be monitored;

f) a description of the measurement systems, and the specification and exact location of the measurement instruments to be used for each of the source streams to be monitored;

g) evidence demonstrating compliance with the uncertainty thresholds for activity data and other parameters (where applicable) for the applied tiers for each source stream;

h) if applicable, a description of the approach to be used for the sampling of fuel and materials for the determination of net calorific value, carbon content, emission factors, oxidation and conversion factor and biomass content for each of the source streams;

i) a description of the intended sources or analytical approaches for the determination of the net calorific values, carbon content, emission factor, oxidation factor, conversion factor or biomass fraction for each of the source streams;

j) if applicable, a list and description of non-accredited laboratories and relevant analytical procedures including a list of all relevant quality assurance measures, e.g. inter-laboratory comparisons;

k) if applicable, a description of continuous emission measurement systems to be used for the monitoring of an emission source, i.e. the points of measurement, frequency of measurements, equipment used, calibration procedures, data collection and storage procedures and the approach for corroborating calculation and the reporting of activity data, emission factors and alike;

l) if applicable, a comprehensive description of the approach and the uncertainty analysis, if not already covered by items (a) to (k) of this list;

m) a description of the procedures for data acquisition, handling activities and control activities as well as a description of the activities;

n) where applicable, information on relevant links with activities undertaken under the EU ecomanagement and audit scheme (EMAS) and other environmental management systems (e.g. ISO14001:2004), in particular on procedures and controls with relevance to greenhouse gas emissions monitoring and reporting.

Similar to the IPCC Good Practice Guidance, the ETS monitoring and reporting guidance is based on a tier system which defines a hierarchy of different ambition levels for activity data, emission factors and oxidation or conversion factors. The operator must, in principle, apply the highest tier level, unless he can demonstrate to the competent authority that this is technically not feasible or would lead to unreasonably high costs. The reported emissions of each installation are verified by independent verifiers for each plant in each reporting year.

1.1.3 EUETS in the United Kingdom

There are EUETS permits for 740 Installations in England and Wales, and a UK wide registry for 1,050 installations. These installations account for about 50% of UK CO_2. But is it unlikely this level of direct substitution of EUETS installation data will ever be possible in the inventory, and considerable work remains to understand the differences between the data returned under the ETS, energy balance in UK energy statistics and emissions reported from other environmental regulators.

Currently the main approach to EUETS data verification is via:

- Good quality reporting templates
- Simple permit, but detailed monitoring plans
- Independent, accredited verification of annual emissions.

Electronic systems are in place for permit application and issue, annual reporting, verification, annual improvement reports, and inspections. Further details are available on the UK web sites of the Environment Agency and the Department of Energy and Climate Change.

1.1.4 The ETS UK specific emissions factor list

EUETS data offers the potential to provide information to improve the UK GHG inventory. The GHG inventory also provides data to the ETS to help operators make estimates of their emissions.

The UK provides tables of emission factors and calorific values for use in annual emissions reporting for the EUETS. The national factors are Tier 2 and Tier 2a emission factors and net calorific values for specific fuels used by particular industries. The data have largely been taken from the UK greenhouse gas inventory.

The factors in these tables should only be used in accordance with the requirements in an installation's approved monitoring plan, which is part of the Greenhouse Gas permit.

1.1.5 What do the 2006 GLs say about using ETS data in GHG inventories?

The 2006 GLs say little about using emissions trading data in the GHG inventories. In Section 2.3.3.2 of the stationary combustion guidelines, the GLs note that:

> *"Tier 3 estimates incorporate data at the level of individual facilities, and this type of information is increasingly available, because of the requirements of emissions trading schemes. It is often the case, that coverage of facility level data does not correspond exactly to coverage of classifications within the national energy statistics, and this can give rise to difficulties in combining the various sources of information. Methods for combining data are discussed in Chapter 2 of Volume 1 on General Guidance and Reporting."*

In Section 6.5 of the chapter on quality assurance / quality control and verification, the GLs note that:

> *"Also, there are guidelines for corporate and entity level QA/QC and verification techniques, which may be reflected in the overall inventory QA/QC process for categories whose estimates rely on data prepared under those guidelines. Examples of such guidelines include the Greenhouse Gas Protocol developed by the World Business Council for Sustainable Development and the World Resources Institute (The greenhouse gas protocol – A corporate accounting and reporting standard. ISBN 156973-568-9), the Guidelines for the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC, as well as a variety of other regional and national guidelines for emissions trading and reporting systems."*

Directive 2003/87/EC is the original EUETS directive.

1.2 Sources of energy data used to compile the UK GHG inventory

The UK greenhouse gas (GHG) inventory uses a wide range of energy related data. This includes energy commodity balance data (published in the UK as national statistics), data reported directly from industries and via trade associations and recently, starting in 2007, data reported under the EUETS. The energy statisticians also use ETS data in certain sectors to help improve the accuracy of statistics they estimate and report. Energy statistics are reported annually in the UK in the Digest of UK Energy Statistics (DUKES).

The Inventory Agency (AEA Technology), working under contract to the UK Department of Energy and Climate Change (DECC), the Single National Entity, conducts a programme of data quality control and assurance which include comparison of emissions data reported under different mechanisms.

There are many different data reporting mechanisms within the UK that report annual atmospheric emission estimates from industrial and other sources, some of which also include estimates of energy use. These different reporting systems frequently quote similar, but numerically different estimates, and occasionally conflicting estimates of emissions. These reasons for the differences in these emissions need to be understood before ETS data can be used in the GHG inventory. Mainly because of this, currently in the UK, emission estimates for greenhouse gases are, to a large extent, independent of EUETS data. However these data are beginning to be used for some key sectors such as the electricity generation sector. The range and extent of emissions and energy data that the GHG inventory compilers use includes:

EUETS data, and sources that use some EUETS data

- CITL - Community Independent Transaction Log data, covering installations operating within the EU Emissions Trading Scheme (EUETS) (*carbon dioxide only, aggregated by site*);
- Detailed EU ETS data (*fuel consumption data by site and fuel type*);
- Energy statistics from the Digest of UK Energy Statistics ("DUKES"), published annually by DECC (*fuel consumption data by sector and fuel type*).

Other energy use data

- Emissions reporting to the UK environmental agencies under the Integrated Pollution Control (IPC) and Integrated Pollution Prevention and Control (IPPC) regimes [i.e. the Pollution Inventory (PI) of the Environment Agency for England and Wales, the Scottish Pollutant Release Inventory (SPRI) of the Scottish Environment

Protection Agency, and the Inventory of Statutory Releases (ISR) of the Northern Ireland Environment Agency] *(GHG and AQ pollutants, aggregated by site)*;

- EEMS - Environmental Emissions Monitoring Scheme data for oil and gas producers operating on the UK Continental Shelf *(GHG and AQ pollutants, by site and by source)*;
- UKPIA data - Emissions data from the United Kingdom Petroleum Industry Association (UKPIA), covering 'complex' crude oil refineries *(GHG and AQ pollutants, split by combustion and process sources, by site)*;
- Corus data - Emissions data from Corus UK Ltd, covering the UK's three integrated steelworks *(GHG and AQ pollutants, by source and by site)*.

Examples of the type of data that are available via the CITL (publically accessible), from detailed ETS returns by the operators (commercially confidential), and from the database of emissions compiled by the UK Environment Agency (commercially confidential) are given in Annex 1, Annex 2 and Annex 3. The usability of these data in the GHG inventory is discussed in Section 1.3.1 of this paper.

The following sections of this paper summarise a comparison of the UK GHG inventory estimates of CO_2 emissions with data reported under the EU ETS. The papers concentrates on CO_2 emissions from combustion and the analysis is based on the 2007 GHG inventory, reported in the 2009 National Inventory Report (NIR).

1.3 General barriers to using ETS data

There are several general barriers that make the job of using the ETS datasets complicated, including:

- Data reporting format: by source, by fuel, by site, by sector.
- Coverage of installations within a given economic sector: comprehensive or limited.
- Reporting protocol for carbon dioxide: thermal, chemical and biological carbon.
- Allocation of installations to emission categories.

The points in the list above are considered in more detail in the following sections below.

1.3.1 Data reporting format

There is a fundamental difference in the requirements of emissions reporting within a GHG inventory reported to the UNFCCC, and the data sets gathered for UK regulatory purposes, for example the EUETS. The format for the GHG inventory is internationally agreed to ensure comparability of data across counties. The reporting is at source-specific level using source categories defined by the IPCC and adopted by the UNFCCC; in contrast, the EUETS reporting contains installation specific data.

The issues around the data reporting format are highlighted below, using examples of the chemical industry and the iron and steel industry.

Figure 1-1 below shows the differences in the boundaries of the reporting regimes of a hypothetical set of chemical sites, and the differences in reported emissions that will be caused by these boundaries.

Figure 1-1 Data reporting comparison of IPPC compared to GHG inventory for part of the <u>chemical industry</u>

	National Energy Statistics (chemicals: gas)	National Energy Statistics (chemicals: oil)	National Energy Statistics (chemicals: biomass)	National Activity Data (flaring)
EUETS (1): Large chemical site	gas combustion	oil combustion	biomass combustion	flaring
EUETS (2): Large chemical site	gas combustion	oil combustion	biomass combustion	flaring
NON-EUETS: Small chemical site	gas combustion	oil combustion	biomass combustion	flaring

The GHG inventory should report all emissions from the chemical sites. In Figure 1-1, this would include the sum of emissions all the sites (large chemical sites and small chemical sites) within an industry sector.

The required scope for data reporting under ETS is defined by the blue boxes in the top part of the figure, and includes fuel use and estimates of emissions from each site included in the ETS. In the figure, the fuel uses (gas, oil and biomass combustion) from the two ETS sites (at the top of the figure) are reported in the UK national energy statistics (DUKES), and via the ETS returns. Fuel use from flaring in chemical industry is not explicitly reported in DUKES, and historically has been estimated by the GHG inventory team from data supplied directly by industry. This estimation is necessary because refinery off-gases (OPG and other gases) are not well tracked in UK energy statistics. A key benefit of the ETS reporting in the UK is that fuel uses and emissions from flaring are now directly available to the UK GHG inventory, and can be used to improve the accuracy of the estimates of the emissions from this sector.

At the bottom of the figure, with a boundary demoted by a blue dotted line, is a small chemical site which is not covered under the ETS. Some of the fuel use from this site would be included in the UK national energy statistics, but the flaring would not. The omission of this site from the ETS highlights the point that the whole sector must report to the ETS before it is possible to consider replacing emissions in the UK GHG with ETS data.

Emission estimates in the GHG inventory cover UK-wide sources such as the total emissions from coal combustion across all of the UK power stations, or emissions from all of the calcination of limestone in the UK's cement kilns. The example of reporting by the iron and steel industry under the ETS and the problems of the using the ETS data in the GHG inventory are shown in Figure 1-2.

Figure 1-2 Data reporting comparison of IPPC compared to GHG inventory for part of the <u>iron and steel industry</u>

		IPCC estimate 1A1c (coke oven)	IPCC estimate 1A2a (site power plant)	IPCC estimate 2C1 (process emission)
EUETS estimate (1)	Iron & Steel Site 1	coke oven energy conversion	fuel combustion	Process source: decarbonisation
EUETS estimate (2)	Iron & Steel Site 2	coke oven energy conversion	fuel combustion	Process source: decarbonisation
EUETS estimate (3)	Iron & Steel Site 3	coke oven energy conversion	fuel combustion	Process source: decarbonisation

Data in the CITL are given by site or installation, and it may be difficult to identify emissions according to the activity responsible, for example from combustion related emissions, or from process related emissions. In the example above, it would be difficult to separate the emissions from the fuel combustion in the coke ovens and site power plant (reported under 1A) from the process emissions reported under 2C1 in the ETS returns.

In summary, the emissions data in the GHG inventory groups together multiple sites (in this case all iron and steel plants), while the data in the CITL group together multiple emission sources (in this case combustion and process emissions).

Some other UK datasets are a hybrid of these two extremes, where some level of detail is available for site-specific emissions by source type. Examples include:

- EEMS. The UK's Environmental Emissions Monitoring System; EEMS is the environmental database of the UK Oil and Gas industry. Oil and gas installations report to DECC, providing site-specific annual estimates that are broken down into sources such as: gas combustion, oil combustion, process sources, fugitives, flaring, venting, well testing;
- UK Petroleum Industry Association (UKPIA). Refinery data are provided to present emissions by installation, with separate figures for the combustion and process sources of the oil refining processes.
- Corus. Iron and steel integrated steelworks data are provided that present a breakdown of IPPC emissions data across the different process units on site including: coke ovens, sinter plant, BOS plant, stockpiles.

Examples of the type of data that are available via the CITL (publically accessible), from detailed ETS returns by the operators (commercially confidential), and from the database of all emissions compiled by the UK Environment Agency, the UK ETS regulator, (commercially confidential) are given in Annex 1, Annex 2 and Annex 3.

Annex 1 shows CITL data; this contains verified emissions from each installation. The CITL data alone will not provide enough data for the GHG inventory compilers. Annex 2 has an example of the detailed returns that a refinery, participating in the UK ETS, makes to the UK Environment Agency. These detailed returns provide a much richer source of data for inventory compilers, and include information about the complexity (Tier) of the method used to estimate the emissions, the fuel consumptions, their carbon contents, calorific values and oxidation factors. Information about carbon contents is particularly valuable as in many cases operators have detailed fuel quality analytical programmes in place and hence the carbon contents are known very accurately. There is also some information about the processes at the reporting site; for example “flare1”, which presumably would mean a flare at the refinery, and “RFG” which means a process using refinery fuel gas[10].

Annex 3 has an example of the detailed ETS data that the UK GHG inventory team is now able to access which is supplied from a database that the UK Environment Agency maintains in its role as the ETS regulator. Using this example, below is a commentary on the information that the data can provide to the UK GHG inventory:

- FuelType Some of the fuel nomenclature is clear, and identifying some of the fuels is easy, for example RFG (OPG). The identities of other fuels need be guessed, for example GO - maybe gas oil? The composition of some fuels is unclear, for example F13.
- ActivityTier / ActivityData No Tier information is provided for some records, but in most cases this affects only the smaller levels of activities (fuel consumption). The GHG inventory team can analyse the Tier information reported to provide an indication of the accuracy of the estimate.
- NCVData Net Calorific data. This field has provided a secondary means to identify fuel type as the GHG inventory compilers can make an assumption of the type of fuel from its NCV.
- EFData / EFTier Emission Factor data. Emissions factors are mostly Tier 3, and this implies high accuracy.

The UK GHG inventory now uses some carbon emission factor data from the ETS to improve the accuracy of the GHG emissions. For example, the carbon emission factors from coal use in power stations are now taken from the ETS returns, as all the UK coal burning power stations report their carbon contents of coal using a Tier 3 methodology, and these data are updated annually.

For sources such as power stations, official energy statistics are likely to be good, and so ETS data can mainly help to improve emission factors. In the case of carbon from catalytic crackers, official energy statistics are likely to be based on estimates. For ETS reporting, carbon emissions are directly measured from crackers. Using ETS data for this source in the UK GHG inventory reduces the uncertainty both from the activity data and the emission factors used in the inventory.

The examples above show that for many sectors GHG inventory emission estimates can only be compared with other source data at an aggregated level, combining both multiple sites and multiple emission sources. The individual installation data given in most of the data sets must always be aggregated up before comparison with GHG inventory data. In some cases, multiple source categories in the GHG inventory must also be aggregated to make a comparison possible. For example, in the cement sector, GHG inventory estimates of CO_2 emissions from fuel combustion must be summed with estimates of GHG inventory estimates of CO_2 emissions from the decarbonisation of limestone before they can be compared against the sum of emissions reported for the entire cement sector.

The publically available ETS data, accessible via the CITL, is of very limited use to the compilers of GHG inventories. Inventory compilers need to gain access to the more detailed data that is available to the in-country regulators of the ETS. This detailed data will contain information that will help in the compilation of the GHG inventory, and will include estimates of emissions, fuel use, and carbon emission factors. It is important to consider the Tier that has been used; the higher Tier data is the most valuable. Just because data is reported in the ETS does not imply that it is immediately suitable for use in a national GHG inventory.

1.3.2 Reporting coverage of installations across an economic sector

The analysis Section 1.3.1 has shown that it is necessary to aggregate up the installation-level data in many data sets before they can be used in the GHG inventory, or in an analysis of the differences between estimates of emissions in the

[10] RFG is derived from the crude oil distillation process and is used to fuel boilers, heaters, turbines, etc. RFG is also used as a chemical feedstock (hydrogen source) in some refinery hydrogen plants. Refinery fuel gas composition may vary significantly on relatively short time scales; thus measurements of calorific values and carbon contents must be made at appropriate sampling locations and at sufficiently short time intervals to accurately determine GHG emissions from the combustion.

GHG inventory and the EUETS. Many of the source categories reported in the GHG inventory relate to an economic sector such as cement clinker production or electricity generation. In order to use and compare UK GHG inventory data with other data sets, it is necessary for those data sets to cover all or practically all of the installations in those economic sectors.

This condition is met for those economic sectors that are characterised by a small number of large installations e.g. electricity generation, cement and lime manufacture, crude oil refineries, coke ovens, steelmaking etc. They all included in the EUETS, although there were temporary opt-outs in the UK for some installations during Phase I (2005 to 2007) when those installations that were included in UK Climate Change Agreements (CCAs) were excluded from reporting emissions data under EUETS. The exclusions due to CCAs covered many sites within the cement and lime sectors, limiting the usefulness of the Phase I EUETS data for comparisons against other estimates for those sectors.

A number of very small electricity generation plant on islands off the UK mainland are too small to be included under the EUETS and so no data are available for those sites. The fuels consumed at these sites will be trivial compared with the fuel consumption of the electricity generating sector as a whole so their absence from some data sets is not significant.

Other IPCC source sectors include many small- and medium-sized enterprises that are not subject to IPPC or EUETS. This means that it is not possible to aggregate data in the EUETS to cover all of those source sectors as defined in the UK inventory. For example, the GHG inventory source category ‘other industrial combustion’, IPCC sector 1A2f, covers the emissions from fuel use across all types of combustion equipment from the largest boilers and furnaces down to space heating systems similar to those used in the domestic sector. It also covers a wide range of industry sectors including: non-ferrous metals, chemicals, engineering, papermaking, food and drink. The GHG inventory estimates for this source category therefore cover a very large number of installations reporting to the CITL, but also cover an even larger number of additional installations that are too small to be included the EUETS. It is not possible to make a judgement about what proportion of sectoral emissions might be missing from EUETS data sets. Any comparisons of reported emissions are therefore limited to a quality-checking of de-minimis emissions for the source sector, due to the incompleteness of the sector coverage under the EUETS.

In the UK, the definition used for combustion installations for ETS purposes currently excludes devices such as furnaces, driers etc where the heat from the combustion is used in the device to perform some process such as melting, drying etc. A more detailed description of the sources included by the UK is given in a regulatory impact assessment report produced by DECC (*EU emissions trading scheme (EU ETS) phase II (2008-2012), potential expansion of the scheme. Full regulatory impact assessment, February 2007*)[11].

1.3.3 Reporting protocol for carbon emissions

Both the GHG inventory and the EUETS contain detailed information on the sources of carbon emissions, allowing a distinction to be made between carbon emissions from combustion of fossil fuels and carbon emissions from ‘processes’. EUETS data includes information on the use of biofuels, but no emissions data are included in the CITL data set. However, comparison of the EUETS and the Environment Agency’s Pollution Inventory (PI) data for the same installation can help to identify where carbon emissions reported in the PI might include biocarbon.

Emissions reported under the ETS should exclude emissions from biocarbon. If verified final emissions were used directly from the CITL there should be no risk of including emissions from biocarbon. However, the raw emissions data taken from the more detailed ETS show instances of companies reporting emissions from biocarbon use – either these are errors in the data, or more probably they represent emissions of fossil carbon from fuels that are mixtures of biofuels and fossil fuels. More clarity in the reporting of fuels would help to resolve this issue.

---

[11] In Phase I, a range of interpretations of the definition of “combustion installation”, and therefore the combustion processes included within the Scheme, were taken by Member States. These were termed narrow, medium and broad referring to the level of inclusion of activities. In its decisions on Phase I NAPs, the Commission rejected the use of the narrow definition but accepted both the medium and broader definitions. The UK followed a “medium” approach, defining a combustion installation as a stationary technical unit that burns fuel for the production of an energy product (which could be electricity, heat or mechanical power). Around half of all Member States interpreted the term more broadly (e.g. the Dutch and Danish NAPs), including all combustion units, whether designed specifically for energy production or not. These inconsistent interpretations have led to competitive distortions in certain sectors. Member States and the Commission have therefore recognised the need for more consistency in Phase II. http://www.decc.gov.uk/assets/decc/what%20we%20do/global%20climate%20change%20and%20energy/tackling%20climate%20change/emissions%20trading/eu_ets/publications/ria-expansion.pdf

1.3.4 Allocation of installations to emission categories

Important considerations

The comparison of GHG inventory data with the other data sets requires information or knowledge of the emission sources present within each installation reporting in the EU ETS, so that data for those installations can be compared against the correct part of the UK inventory. For most key emission sources, the UK GHG inventory team have a full understanding of where that source occurs in the UK, and can therefore identify all of these sites in the regulators' and EU ETS data sets (but this is not always a straightforward task however – see sections below). Power stations, refineries, steelworks, cement works, and lime works all fall within this category. In the case of other industrial sites, particularly those associated with chemicals manufacture, it is more difficult to identify what sources are present, without detailed research. The reporting of carbon dioxide emissions is usually a good indication that an installation includes a combustion plant, especially if NO_X emissions are also reported. But other processes can give rise to carbon dioxide, including chemical processes, and waste treatment such as incineration, flaring and effluent treatment. Fermentation processes will also lead to carbon dioxide emissions. As described in Section 1.3.3, PI data include bio-carbon and so emissions from some processes such as breweries may be largely from fermentation.

The following paragraphs provides examples of the approaches taken by the UK GHG inventory compilers to maintain and develop their understanding of the UK industry and to ensure that emissions are correctly allocated to the correct IPCC source sector.

Over the past ten years, the UK inventory team has built up a good understanding of the emitting processes present at many industrial sites. One very useful source of data on installations reporting in the PI was the authorisation documents for processes regulated under IPC in England and Wales by the Environment Agency.

The move from the Integrated Pollution Control (IPC) regime to Integrated Pollution Prevention and Control (IPPC) meant re-permitting of installations by the regulators. In the case of processes regulated by the Environment Agency, this has led to some problems since the relationship of IPC to IPPC permits are not fully understood. We have made some progress towards defining these relationships using data supplied by the EA, as well as additional information such as shared operator names, addresses, postcodes or similarities between revocation dates for IPC permits and start dates for IPPC permits. The mapping of IPC to IPPC permits is not always straightforward: there are many cases where the operator name or address or postcode information that we have for IPC and IPPC installations are different but it appears likely that the permits refer to the same site. While we are confident that our mapping of IPC and IPPC permits is generally accurate, it is very likely that there are some errors or omissions. This highlights the need for the inventory team to maintain close relationships with the industry and to maintain a detailed understanding of the operations at the sites emitting significant quantities of GHGs.

In a few cases, emissions have been reported in the PI for both the revoked, IPC, permit and the IPPC permit that supersedes it. The mapping of IPC to IPPC permits allows these rare cases to be identified and filtered out. This point highlights the need to carefully review data before it is included in the GHG inventory, even after QA/QC measures have been applied by the environmental regulators.

The relationship between IPC/IPPC permits and EUETS installations also needs to be understood, as does the relationship between EUETS installations and sites reporting to EEMS. As with the mapping of IPC and IPPC permits, the UK GHG inventory team have had to build up a mapping to cover all of these. For some sectors, such as the electricity supply industry and cement works, this is relatively straightforward with a single IPC permit, single IPPC permit and (generally) a single EUETS installation.

A complicating factor is that new permits are sometimes issued for sites covered by EUETS, presumably if the organisation responsible for the installation changes. In such cases we have had to use address or postcode data to identify these links. Steelworks are covered by a single EUETS permit and a single IPPC permit so links are easy to make. However, the scope of these permits is different since the EUETS installation does not include rolling mill and heat-treatment furnaces, whereas IPPC permit does.

Industry-specific research

The description below provides a detailed assessment of the complexities of using the ETS data in the UK inventory, and, as an example, refers in detail to the research the GHG inventory team have done to understand the reporting in the oil and gas terminal sectors. One important message from this research was the need to consider relationships of the reporting of emissions in all the emission reporting systems, and not just under the ETS.

The refinery sector provides several examples of complex reporting scope relationships between IPPC and EUETS. Another recent study by AEA has focussed on analysis of emissions data within the refinery and oil and gas terminal sectors[12].

One UK refinery has a single IPPC permit but the processes are split into two parts for the purposes of EUETS, whilst several UK refineries include chemical manufacturing processes within the scope of their IPPC permits, but emission estimates from these activities are outside of the scope of the EUETS and the UKPIA-reported data. The detailed analysis of IPPC permits and emissions data has enabled all site emission allocations to be fully resolved within the GHG inventory and point source database that AEA uses to underpin spatially disaggregated emissions data.

Within the same study, the AEA inventory team has conducted a detailed analysis of the carbon dioxide emissions data reported by oil and gas terminals via three different reporting systems:

- IPPC permits, via the Pollution Inventory and Scottish Pollutant Release Inventory;
- EU Emissions Trading Scheme; and
- The Environmental Emissions Monitoring Scheme (EEMS).

Each of the onshore terminal sites reports voluntarily to EEMS, and the data format in EEMS provides a limited insight into the split of emissions by source for these installations. There are no defined permits under EEMS, although the regulator (DECC Oil and Gas) provides guidance on emissions reporting, which ensures some degree of reporting consistency between sites. The recent research has enabled a detailed review of IPPC permits for the sites, as well as direct consultation across the regulators of EUETS, EEMS and IPPC, to help analyse in details site-specific data reporting inconsistencies and try to resolve them. In most cases, the reasons for data discrepancies have been identified and the allocation of emissions within the GHG inventory resolved.

Further to this research aimed at the onshore oil and gas terminals, a limited review of the emissions reported via EEMS and EUETS has been initiated for the offshore oil and gas installations. An initial comparison of CITL data against EEMS data has identified a series of inconsistencies for carbon dioxide emissions, including several sites that are evident in one system but not the other. The DECC Oil and Gas team in Aberdeen regulates both EEMS and EUETS for the offshore sites, and hence these findings have been passed on to DECC and are currently being considered. Currently the data for EUETS emissions under Phase II are only available for 2008. The scope of emissions reporting by oil and gas sites was expanded from Phase I, to now include emissions from flaring (as well as combustion sources, which were included in Phase I). Hence there is a limited dataset for the oil and gas sector, and it is not possible at this stage to take forward any revisions to the GHG inventory data for offshore sites.

In previous years, similar research focus and direct consultation with industry experts has enabled a thorough understanding of the reporting scope under IPPC and EUETS for integrated steelworks. To enable the AEA team to correctly interpret the range of data from Corus plant, a bespoke template for emissions reporting has been developed in conjunction with Corus, which clarifies the relationships and scope of reporting across IPPC and EUETS.

Extending this detailed research and consultation approach to resolve data reporting inconsistencies across other economic sectors is a very resource-intensive process. Within the annual GHG inventory development work programme, the GHG inventory team prioritises areas of data uncertainty and pursues clarifications through a programme of stakeholder consultation. Through a phased improvement in knowledge of IPPC and EUETS permit scopes and consultation with regulators and representatives of major industry sectors, these scope uncertainties are gradually being resolved, but only for the highest-emitting source sectors. The lesson from this is that countries who are aiming to make full use of ETS data need to allocate resources to the analysis of the ETS data, and should not assume it is a trivial task.

[12] http://www.airquality.co.uk/archive/reports/cat07/1005251107_DA_Improvement_Report_Industry_Task_May2010_Issue_1.pdf

2 Comparing UK GHG inventory with ETS combustion CO_2 data

The previous section has outlined the barriers of using ETS data in the UK GHG inventory. This Chapter shows how the UK has been able to use selected data in the GHG inventory. It also presents comparisons of the ETS emissions from selected sectors with GHG inventory data.

2.1 Approach to using ETS data in the UK GHG inventory

When the UK GHG inventory team have assessed whether to use EUETS data in the GHG inventory, we have asked some simple but important questions:

1) How do emission estimates for the UK, given in the GHG inventory, compare with emissions data given in the EUETS, and elsewhere?
2) How consistent are the emissions data reported elsewhere, for example how consistent are data in the UK Pollution Inventory and the CITL?
3) How consistent are the energy statistics reported in the UK Digest of energy Statistics (DUKES), by site operators under EUETS and in the GHG inventory?

In order to answer the **first** and **third** questions, groups of installations are first identified that are comparable in scope to single emission sources or groups of sources in the GHG inventory. Ideally, one would want to be able to compare at a fairly disaggregated level but due to the 'barriers' described in the sections above, this is not always possible. Once a group of installations has been identified, then emissions from these installations can be summed to compare with emission estimates from the GHG inventory.

To answer the **second** question, data at individual site level can be compared. As well as all of the non-GHG inventory data sets, this comparison can also include GHG inventory point source data. The UK inventory programme includes the production of emission maps and other geographically-resolved emissions data for Local Authorities, Devolved Administrations and to underpin air quality dispersion modelling studies.

In the full analysis, the GHG inventory team used a wide range of data:

- Regulators' inventories (PI, SPRI, ISR)
- **CITL (EUETS)**
- Corus (where applicable)
- UKPIA (where applicable)
- EEMS
- **GHG inventory i.e. UK level emission estimates**
- GHG inventory CO_2 emissions for Type 1 points – site specific data consistent with the UK total
- GHG inventory CO_2 emissions for Type 0 points – site specific data based on detailed analysis of data reported in the non-GHGI data sets and therefore not consistent with the UK total.

The analysis in this paper concentrates on just the emissions from the UK GHG inventory and the CITL (highlighted in bold in the list above).

The detailed analysis for greenhouse gases relate to the 2007 reporting year, presented in the 2009 National Inventory Report.

2.1.1 How has validation and QA/QC been dealt with?

The EUETS data is carefully reviewed by the GHG inventory team before any data from the detailed ETS returns are included in the GHG inventory. This review includes a comparison with other sources of data from the regulatory agencies; for example, see the example of the analysis of the data reported by refineries towards the end of **Section** 1.3.4. Further comment about the process of the detailed review of the EUETS data is made in the sections below.

Once the GHG inventory is prepared, it is subject to a formal review by the UK national GHG inventory steering committee before the UK inventory is formally submitted to the UNFCCC.

2.1.2 Comparison of emissions from combustion in the ETS with three sources in the UK GHG inventory

The next sections provide a detailed comparison and interpretation of the differences between the 2007 UK GHG inventory estimates from four important sources, and the corresponding data from the EUETS returns. The comparison includes sources where there is very good agreement between the UK GHG inventory and the EUETS, and sources where there are important differences. Sources less that about 2% of the UK CO_2 emissions are not considered.

In the sections below, in comparisons between CO_2emissions and the national total CO_2emissions, the national total CO_2 emissions include net LULUCF.

2.1.3 Power stations

Carbon coal-fired and oil-fired power stations

According to the 2007 UK GHG inventory, coal-fired and oil-fired power stations emitted 20% of UK CO_2 in 2007.

Coal-fired and oil-fired power stations are considered together because oils are used as start-up fuels for coal-fired stations and therefore a significant proportion of oil burnt in power stations is burnt at those stations which burn coal as the primary fuel. The GHG inventory emissions data for coal burnt in power stations is therefore not strictly comparable with the non-GHG inventory data for coal-fired stations, because the latter also includes emissions from the burning of oil during start-up. Similarly, the GHG inventory emissions data for oil burnt at power stations is not comparable with the non-GHG inventory data for oil-fired power stations. Considering coal and oil-fired power stations together minimises differences in scope between GHG inventory and non GHG inventory data. Note that natural gas is also used as a start-up fuel at coal-fired power stations, but the quantities are very small in comparison to the quantities of gas burnt in gas-fired power stations, and so gas use and gas-fired power stations are compared separately.

Table 2-1 shows the total emissions from coal-fired and oil-fired power stations in the various data sets.

Table 2-1 Emissions from coal/oil-fired power stations (ktonnes CO_2)

Coal/oil fired power stations		
IPPC regulatory inventories	CITL (EUETS)	GHG inventory
119,625	118,664	117,836

The scope of reporting of power station activities is broadly consistent across all reporting mechanisms, and the GHG inventory estimates are derived from emission factors from EUETS data, and hence good agreement across all reporting mechanisms is achieved. There are some small differences in emissions reported from the data sets, which are, due to:

IPPC regulatory inventories include emissions of bio-carbon, at sites where co-firing of biofuels occurs. As a result, the IPPC data are slightly higher than the emissions reported under EUETS.

The GHG inventory figure is based on (i) emission factors from EUETS data, and (ii) fuel consumption data from the Digest of UK Energy Statistics (DUKES). Analysis has shown that the activity data in DUKES is not fully consistent with the fuel use data reported within EUETS, which underpins the emission estimates reported in the CITL, and hence there is a small inconsistency in emissions data. The IPPC data may also include emissions from the burning of natural gas as a start-up fuel.

Taking into account these factors, then the small differences in the figures from the different sources are at least partially explicable. Although there would still be a residual difference between the GHG inventory and the non-GHG inventory data if corrections could be applied for these factors, it seems likely that this residual difference would be small and that the GHG inventory and non-GHG inventory data sets are in close agreement.

Gas fired power stations

According to the 2007 UK GHG inventory, gas-fired power stations emitted 10% of UK carbon in 2007.

The group of gas-fired power stations includes Peterhead, which burns a small amount of ‘acid’ gas (gas with a higher than normal content of acidic gases including H_2S and CO_2), and also includes some conventional dual-fuel steam stations as well as gas turbine stations. Many of the stations burn small quantities of petroleum-based fuels including gas oil and LPG, and one station burns colliery methane, which is absent from the GHG inventory figures (all colliery methane is allocated to industrial sites). Table 2-2 shows the total emissions from gas-fired power stations in the five data sets.

Table 2-2 Emissions for gas-fired power stations (ktonnes CO_2)

Gas-fired power stations		
IPPC regulatory inventories	CITL	GHG inventory
59,250	59,154	58,564

As with coal/oil-fired power stations, there are relatively small differences between the data. The CITL figure is slightly lower than the figure given in the regulators' inventories, although a number of very small power stations do not report in these inventories, so one might expect the CITL figure to be the higher of the two. The reason why this is not so is not clear but it is most likely due to small differences in scope at some installations, or due to inconsistent reporting.

A detailed analysis has been made (but not reported here) of site-specific data for those gas-fired power stations where there was least good agreement between the various data sets. The analysis suggests that the CITL data is more reliable that the data taken from regulators' inventories.

2.1.4 Integrated steelworks

According to the 2007 UK GHG inventory, integrated steelworks and coke ovens emitted 4% of UK carbon in 2007.

The UK has three integrated steelworks which incorporate coking, sintering, blast furnaces and steel production using the basic oxygen process. These steelworks are owned by Corus. It is necessary to add the UK's only remaining standalone coke ovens (operated by Monckton Coke & Chemical) to this group in order to ensure a more consistent scope in the various data sets. Table 2-3 shows the total emissions from steelworks and coke ovens reported in the various data sets.

Table 2-3 Emissions for integrated steelworks (ktonnes CO_2)

Integrated steelworks			
IPPC regulatory inventories	CITL	Corus	GHG inventory
21,776	20,486	21,677	21,355

The agreement between the total emissions from the CITL and the GHG inventory is reasonable. There are considerable differences between the emissions totals from different sub-sources; however there are some factors that help to explain at least some of these differences. Generally, these are to do with the scope of the estimates.

The figures from the regulator's inventory and from Corus are believed to cover all or at least the most significant sources of carbon emissions at each site. The main difference between the two is then the inclusion of Monckton's coke oven in the Pollution Inventory data but not included in the Corus data. The site-specific data are actually somewhat different in the case of two Corus sites but these largely cancel out in the totals. These differences are thought to be due to changes in methodology between reporting to the Pollution Inventory and the later compilation of the Corus data set.

The CITL data do not include emissions from rolling mill furnaces and reheat furnaces, whereas the Pollution Inventory and Corus data do, therefore the CITL figure is lower.

The GHG inventory estimate is based on national activity data and emission factors and will not necessarily be consistent with the non-GHG inventory data sets. But the level of agreement with the Corus and regulator's inventory is good. There is one area where the scope of the estimates may be slightly different – the GHG inventory groups all iron & steel industry use of fuels in boilers and furnaces together and this fuel use will include fuel used at Corus' integrated steelworks, Corus' other works, and fuel used by numerous other process operators, most of them running small foundries. In this analysis we have included all emissions from use of coke oven gas and blast furnace gas in the figure shown in Table 2-3, but excluded all emissions from coke, fuel oil, natural gas, and other, minor, fuels on the basis that the majority of usage is likely to be at other sites. Some natural gas and fuel oil may actually be used at the integrated works, so the GHG inventory figure would then underestimate actual emissions.

Table 2-4 compares data from Corus and from the GHG inventory, broken down by emission source. The difference in the figures for basic oxygen furnaces stands out as the most significant discrepancy between the two sets of data. The difference is at least partly explained by inconsistencies in the scope. The GHG inventory figure only covers carbon dioxide derived from dolomite added to the oxygen furnace, and electrode emissions in ladle arc furnaces. The Corus figure also includes emissions from casters, ladle heating and, perhaps most importantly, emissions from oxygen blowing. In the GHG inventory these are treated as part of the overall carbon balance and so the carbon contained in the basic oxygen furnace-off gas is treated as entering the steelworks fuel gas supply and then emitted from the coke ovens, blast furnaces and combustion plant (with some possibly being included in the flaring/losses figures). A more detailed breakdown from Corus would help to determine whether the discrepancy noted is solely due to differences in scope or whether there is a serious problem with one or other set of data.

Table 2-4 Emissions for integrated steelworks, broken down by source type (ktonnes CO_2)

Data by source		
Source	Corus	GHG inventory
Coke ovens	1,206	1,320
Sintering	2,988	2,977
Blast furnaces	4,495	4,631
Basic oxygen furnaces	1,547	136
Flaring/losses	1,613	2,127
Combustion	9,827	10,168

Given the issues outlined above for the basic oxygen furnace numbers, it is not possible to draw any conclusion from the much smaller differences between the GHG inventory and Corus figures for the other sources, although the GHG inventory figure for coke ovens does contain emissions for Monckton and therefore should be larger than the Corus figure.

An important question to answer is is it possible to use the detailed ETS data to identify the emissions from combustion alone in this sector? For the UK it is not possible to isolate combustion emissions from the whole iron and steel sector; it is possible to identify combustion emissions from coke ovens and sintering processes, but not from blast furnaces[13].

Table 2-5 shows total emissions data for individual installations.

Table 2-5 Emissions for integrated steelworks & cokeovens (ktonnes CO_2)

Data by site			
Installation	Regulators' inventories	CITL	Corus
Corus Port Talbot	7,348	7,058	7,557
Corus Scunthorpe	8,081	7,172	7,828
Corus Teesside	6,299	6,211	6,296

[13] In Table 2-4, based on the way we report emissions in the UK GHG inventory, the coke ovens line will mainly be 1A1c, but with possibly some emissions from 1B1b, the blast furnace line will cover 1A2a but also 2C1, but the combustion lines will be solely 1A2a. The remaining lines are not combustion.

Data by site			
Installation	Regulators' inventories	CITL	Corus
Monckton Coke & Chemical	51	44	-

The data for individual sites show the same features which have already been discussed above – a small discrepancy in reported emissions for two Corus sites, and lower emissions in the CITL due to the exclusion of furnace emissions from these data.

2.1.5 Refineries

According to the 2007 UK GHG inventory, refineries emitted 3% of UK carbon in 2007.

The refineries group includes both the nine 'complex' UK refineries, but also three smaller, specialised, refineries. Table 2-6 shows the total emissions from refineries reported in the various data sets.

Table 2-6 Emissions for refineries (ktonnes CO_2)

Refineries		
IPPC regulatory inventories	CITL	GHG inventory
18,319	17,813	15,004

There are some differences in scope between the IPPC installations and those covered by EUETS, with some chemical manufacturing processes included in the IPPC installation for Stanlow. A further known issue is that carbon emissions data for North Tees were revised subsequent to reporting to the PI and so the PI figure can be considered less reliable. Both factors help to explain the fact that the figure from the regulators' inventories is higher than the one from the CITL. One small refinery (Eastham) has not reported carbon dioxide emissions in the PI and this cancels out the impact of the other two issues to a small extent. The data from UKPIA does not cover the three small refineries, so the fact that the figure from UKPIA is lower than the figures from the CITL and the regulators' inventories is not surprising.

The GHG inventory figure is significantly lower than any of the non-GHG inventory data. Detailed analysis of the EUETS dataset (Thistlethwaite & Passant, 2009) have identified a number of areas of difference between EUETS and GHG inventory figures.

Most importantly, EUETS emissions data for catalyst regeneration are significantly higher than those given in the GHG inventory. The GHG inventory methodology was modified for the latest (2007) version, in order to reduce this difference, but was constrained by the energy data in DUKES (i.e. the GHG inventory emission estimate assumes that all of the 'petroleum coke' given in DUKES is 100% carbon and 100% emitted). Full use of EUETS data in the GHG inventory would require the GHG inventory to diverge from the UK energy statistics e.g. by assuming that some of the non-energy use of petroleum coke listed in DUKES is actually burnt off during catalyst regeneration. There are precedents for divergences such as this e.g. lubricants, coal tars and benzoles etc. but one unique issue in this case is that the DUKES fuel 'petroleum coke' actually covers three quite different products:

Green (uncalcined) petroleum coke, imported into the UK, and used as a fuel (solid smokeless fuel, cement kilns, power stations);

Anode grade (calcined) petroleum coke, produced at South Killingholme and perhaps also imported, and used to manufacture products such as anodes for the aluminium industry;

Carbon deposits on catalysts e.g. in catalytic crackers which must be burnt off periodically to 'regenerate' the catalyst.

While the first two are linked in that they are both products of a refinery process called a coker, with anode grade coke undergoing a further treatment stage, the third product is unrelated. Currently DUKES seems to include the first two in the non-energy part of the commodity balance table, with only the final product appearing as an energy use. Increasing the GHG inventory activity data beyond that given in DUKES by transferring petroleum coke from non-energy usage to energy usage would, in effect, mean changing one product into another, and not just changing the assumptions about how a given product is used in the UK.

A decision was taken for the 2008 inventory to make the GHG inventory consistent with the EUETS data, therefore diverging from the DUKES total.

A second issue is that consumption of fuel oil and OPG given in DUKES do not agree with the figures that can be derived from the EUETS data (although there are some slight problems with allocating fuels listed in EUETS data to the fuel categories used in DUKES). There are also significant differences between carbon factors used in EUETS for OPG and the emission factor used in the GHG inventory. The overall impact of these differences is that the GHG inventory has a significantly higher estimate for carbon from fuel oil, and a significantly lower estimate for carbon from OPG, although these almost cancel each other out.

2.1.6 Other combustion plant

According to the 2007 UK GHG inventory, other combustion plant emitted 15% of UK carbon in 2007.

This group includes other combustion plant across the UK and on the UK continental shelf, as well as other emissions from oil & gas installations. In the case of this group, emissions data are not complete for any of the data sets except the GHG inventory, and the scope of some of the data sets are sometimes very different e.g. EEMS covers offshore installations and terminals only, whereas the regulators' inventories cover numerous onshore combustion processes, some terminal emissions and no offshore emissions. Emissions are summarised in Table 2-7.

Table 2-7 Emissions for other combustion plant & offshore installations (ktonnes CO_2)

Other combustion plant and offshore installations			
IPPC regulatory inventories	CITL	GHG inventories	EEMS
35,820	31,277	93,797	19,936

As would be expected, emissions in the GHG inventory exceed emissions in the other inventories by a considerable extent. This can be explained by the fact that the GHG inventory figure includes emissions from all sources including both onshore and offshore sites, and all plant including those which would be too small to be included in the regulator's inventories or the CITL. The scope of EEMS, the CITL and the regulator's inventories are sufficiently different that the emission totals should not be expected to be similar. The GHG inventory point source data include emissions data taken from EEMS, CITL and the regulator's inventories and so the total emission is larger than for any of those three data sets, but is still much lower than the GHG inventory. This is because the point source data only covers the largest combustion plant.

2.1.7 Summary

For refineries and power stations, the UK is able to use detailed ETS data to identify CO_2 emissions associated with combustion. The ETS reporting in the iron and steel sector does not allow emissions from combustion to be fully separated from other emissions.

2.1.8 Specific examples of problems and issues

This section provides a summary of the problems that have been encountered as the UK inventory team now tries to use the EUETS data in the UK GHG inventory. These points have been covered in more detail in the previous sections.

The EUETS has provided a rich source of data to the GHG inventory compilers, but problems still remain at technical and administrative levels, for example:

- Access to data. EUETS raw data on energy use and emissions by source is not always freely available at full detail to the Inventory Agency. Publically available data from the CITL is of very limited use to inventory compilers.
- Formats and aggregation of sources. EUETS emissions data is reported at an installation-level, which may aggregate many different process and combustion sources. This limits the detail of reporting aligned to IPCC format. It may be possible to identify combustion related emissions from process related emissions at some,

but not all sites. This leads to complexities when it comes to analysis of “traded” and “non-traded” emissions within GHG inventories, which is an increasing requirement across the EU, as all Member States are signing up to fixed contributions to emission reductions in the “non-traded” source sectors (under the EU Effort Sharing Decision).

- Coverage of sources. The scope of EUETS does not cover all sites within a given industrial sector e.g. in the UK the EUETS covers 100% of power stations and refineries, but does not cover all lime kilns, all chemical sites etc.
- UK implementation of the ETS. In Phase I EUETS (2005-2007) the UK took a narrower definition of “combustion” than other Member States. It *excluded* furnaces and driers (e.g. metals industry, food & drink, chemical. It *included* boiler plant on industrial sites, raising steam for a reactor vessel. This definition does hinder incorporating ETS data in the GHG inventory, and makes comparison with ETS data from other countries more problematic. In Phase II (2008-2012) the scope of EUETS has expanded, and now includes sources such as flaring at oil and gas sites.
- Nomenclature. Fuel naming nomenclature in the EUETS is not rigidly defined, and there is no mandatory requirement for agreement with the IPCC nomenclature. Operators may use fuel names that are useful to them, but which may be unclear or unrecognisable to GHG inventory compilers.
- Commercial confidentiality. A problem in several Member States and also where local / regional emissions data are to be derived. Where one or two plant in a given economic sector are reported in isolation, this is problematic. In the UK, the Inventory Agency can get full access to the fuel-specific data, but the data cannot be released to a wider audience. Some data will commercially confidential; formal data supply agreements specifying the protocols for dealing with commercially confidential data may help secure access to data for the inventory compliers.
- Variable data quality. EUETS data (fuel use, emission factors and calorific values, and methodological approach) are estimated using a Tiered approach, in an analogous way to the IPCC approach. Data are subject to verification and possible external audit. GHG inventory compliers should not assume that EUETS data are necessarily more accurate that the data used in GHG inventories; attention should be paid to the Tier used to generate the data. There are some example of variable application of EUETS data verification by accredited organisations – for example, unlikely outliers in natural gas carbon content in UK.
- Coverage of GHGs. Only CO_2 is reported in the UK, although there is the provision for other GHGs to be included currently in the regulations.
- Extent of time series. Good quality data is available from 2005 onwards only and this creates time-series consistency concerns. How best to back-calculate data for earlier years in the time-series?

2.1.9 Specific examples of good practice

It is good practice to carefully review the ETS data and to understand its limitations and then consider what ETS data could be used in the inventory. It is not good practice to just replace GHG inventory data with ETS data without any review of the ETS data. The UK GHG inventory does now use some ETS data (for example, carbon emission factors for coal use in the energy sector and for some fuels in the refinery sector). The inventory compilers are considering using more ETS data but only after completing a thorough analysis and interpretation of recent ETS data against the GHG inventory. This analysis involves comparing data from the detailed ETS returns against the 2007 GHG inventory itself, and data reported by other environmental regulators. Only the highest Tier ETS data are being considered for inclusion in the GHG inventory.

The UK has a fully functional national inventory steering committee (NISC). This helps facilitate close cooperation and a good working relationship between the regulators of the ETS in the UK (the Environment Agency), the GHG inventory compilers and other environmental regulators. The NISC allows a formal review of the inventory before it is submitted to the UNFCCC.

2.1.10 Benefits of EUETS to GHG inventories

There are some clear benefits to using ETS data in GHG inventories. The list below provides some specific UK examples:

- Use as an energy statistics quality-check against the national energy data allocations of fuels to sectors. ETS data may reveal new sources / new fuels. Examples:

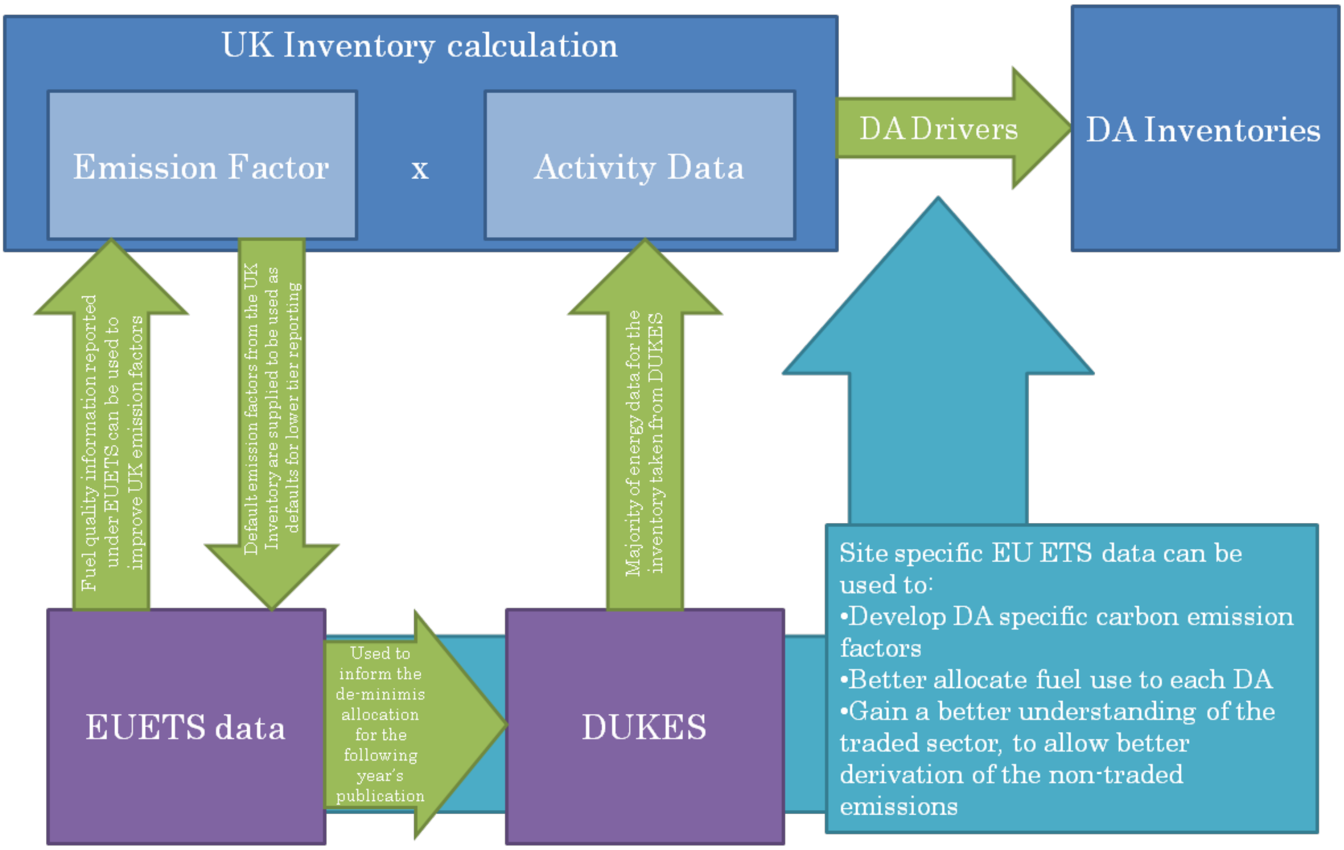
    - refinery RFG, OPG, flaring;
    - flaring data from several sectors (chemicals, oil and gas);
    - use of clays and coke in brick-making and other mineral processes;
    - solvents used as fuels.
- The ETS may provide new activity data and new fuel quality data (from higher Tier reporting). Examples:
    - UK refinery coke use (the UK GHG inventory now deviates from UK energy statistics, as we have identified that the UK energy balance is wrong for the refinery sector for 2006 and 2007. The UK inventory agency has worked with the UK energy statistics team and the UK refinery trade association, to research and resolve the data reporting inconsistencies that were evident.);
    - Use of Tier 3 CO_2 emission factors, GCV data etc for all power station fuels, refinery fuels;
    - New data on fossil fuels and bio-derived fuels, to enable more detailed analysis and clarify emission sources (e.g. to compare against IPPC-reported emissions data);
    - Fuel quality data for Coke Oven Gas and Blast Furnace Gas.
- The EUETS can be used to inform region-specific emission factors and fuel quality data, to inform more local and regional emission inventories, providing more opportunities and data to inform local and regional GHG mitigation opportunities. For example, within the UK, the EUETS data are used to inform the development of emission inventories for each local authority (CO_2 inventories only) and for the devolved Governments of Wales, Scotland and Northern Ireland (full GHG inventories, to meet reporting requirements and policy tracking needs for regional climate change action plans / strategies); see Chapter 3.

3 Use of EUETS data in sub national inventories

3.1 Creating UK sub national inventories

In the UK, GHG inventories for the constituent countries, or Devolved Administrations (DAs) - England, Northern Ireland, Scotland and Wales - are created annually, and rely on data from the UK GHG inventory. It would be possible to use ETS data to help improve the accuracy of these inventories. Figure 3-1 outlines the approach used to estimate emissions for the GHG inventories of the constituent countries of the UK, and shows the specific areas in which ETS data could be used to help improve these inventories.

Figure 3-1 Using ETS data in sub national (regional) GHG inventories



EU ETS data are used to inform the development of detailed official energy statistics (DUKES) in that they provide a minimum value (de-minimus) for the fuel used in certain sectors of industry, and the statisticians check that this is consistent with their independently derived energy consumption data.

The next sections provide two examples to show how detailed EUETS data could be used to help improve the accuracy of sub national inventories in the UK. There is a discussion about the reasons for differences between the different data sources in each section.

3.2 Coal fired power stations

Emissions of CO_2 from coal fired power stations make a large contribution to the total emissions in the constituent countries of the UK. CITL data could be used to improve the accuracy of these estimates. Table 3-1 provides an example of site-specific data that could be used for a selection of power stations. The table shows data where emissions data are most variable across different reporting mechanisms which then allows a discussion about the reasons for this variability.

Table 3-1 Emissions data for selected coal-fired power stations (ktonnes CO_2)

Data for selected coal fired power stations		
Site	IPPC regulatory inventories	CITL
Ferrybridge C	8,822	8,287
Fiddlers Ferry	5,859	5,636
Tilbury B	4,008	4,723
Aberthaw B	4,077	4,187
Drax	22,649	22,161
Kingsnorth	9,090	8,914
Fifoots Point	631	649
West Burton	9,434	9,324

All of the data sets include emissions from Flue Gas Desulphurisation (FGD) systems as well as the combustion of fuels. In the case of Ferrybridge C, Fiddlers Ferry, Drax, Kingsnorth, and West Burton, the data from the IPPC regulatory inventories and the CITL follow a similar pattern to that noted in the data for the group as a whole, with higher emissions reported under IPPC. The differences are in part due to biocarbon from co-fired biomass being included in the IPPC data.

In theory it is possible to identify emissions from the FGD plants in the detailed ETS returns, but this may reveal data that commercially confidential.

In the case of Tilbury B, Aberthaw B, and Fifoots Point, the CITL figure is higher than that given by the regulator's inventory and although the difference is relatively small in the latter two cases, it is a very significant difference in the case of Tilbury B. Emissions data are supplied to regulators at different times for different purposes and different individuals might be involved in preparing and submitting these data sets. Therefore, small differences in numbers might occur due to different data being available (i.e. 'provisional' and 'final' data) or differences in methodology. It seems reasonable to believe that the differences for Aberthaw B and Fifoots Point could be due to a factor such as this (the difference is ~3% in each case). The difference for Tilbury B is 18%, so either any revisions to data or methodology would have to be very significant, there would have to be a major difference in scope, or one or other figure contained an error. Without further information, it is not possible to conclude what reason there is for the difference, although a difference in scope appears the least likely.

3.3 Refineries

Table 3-2 shows CO_2 emissions data for individual refineries.

Table 3-2 Emissions data for crude oil refineries (ktonnes CO_2)

Data by site			
Site	Regulators' inventories	CITL	UKPIA
Coryton	1,929	1,925	1,925
Fawley	3,018	3,018	3,018
Grangemouth	2,240	2,240	2,237
Killingholme	1,764	1,764	1,764
Milford Haven	1,210	1,210	1,206
North Tees	495	260	260
Pembroke	2,449	2,449	2,449
South Killingholme	2,237	2,141	2,141
Stanlow	2,930	2,702	2,702
Dundee	26	25	-
Eastham	-	51	-
Harwich	22	22	-

Three sets of data (regulator's inventories, CITL, and UKPIA generally in close agreement or even identical. Only in the cases of North Tees, South Killingholme and Stanlow is there any significant disagreement between the figures and in all three cases it is the figure from the regulator's inventory which is different. The differences at North Tees and Stanlow have already been explained above. The reason for the difference at South Killingholme is not known with certainty but may be due to the inclusion of an activated sludge biological effluent-treatment plant in the PI which is not included in the EUETS).

4 UK energy data and EUETS data comparisons

Estimates of emissions of carbon emissions in the UK GHG inventory mostly rely on data in the Digest of UK energy statistics (DUKES). If more energy data from the ETS were to be used in the UK GHG inventory, it is important to understand the reasons for any differences between energy consumptions reported in DUKES and via the detailed ETS returns.

A comparison between energy data presented in DUKES and data reported by plant operators as part of EU ETS returns has been completed, and reported in *The DA GHGI Improvement Programme 2009-2010 EU ETS Task (AEA, 2010).* This report was part of the DA improvement programme, and focused on how the EU ETS site specific data could be used to improve both the DA and UK inventories. This report is available from:

http://www.airquality.co.uk/reports/cat07/1005251111_DA_GHGI_Improvement_Report_EUETS_May2010r.pdf

The main findings of this report were that for sectors such as power generation and refineries, where the emissions trading mechanism covers the whole of the economic sector, there is generally a good agreement between DUKES and the EUETS data. However, when comparing fuel use statistics for sectors where not all of the operators are covered by EUETS, some inconsistencies were evident and more fuel use was being reported in the EUETS data set than in DUKES.

UK energy statisticians report that they use EU ETS data to inform the development of detailed official energy statistics (DUKES). In part, they provide a minimum value (de-minimus) for the fuel used in certain sectors of industry, and the statisticians check that this is consistent with their independently derived energy consumption data.

During the Phase 1 EU ETS, from 2005 to 2007, several economic sectors had many sites that were opted-out of EU ETS due to pre-existing emissions trading arrangements within sector-wide Climate Change Agreements (CCAs). However, from 2008 onwards the CCA opt-outs have ceased and hence the number of UK installations operating within the EUETS has increased. This has allowed a more detailed analysis to be carried out for 2008.

A specific example of where the ETS data has helped improved the accuracy of the GHG inventory is the reporting of petroleum coke use.

In DUKES, some petroleum coke is allocated to refineries, and the remainder to non energy use. It is, however, known that petroleum coke is also used as a fuel in the domestic sector, power stations and the cement industry. Analysis of the EU ETS data also indicates an under allocation of petroleum coke to refineries. The UK GHG inventory therefore deviates from both the total petroleum coke use, and the sectoral allocation presented in DUKES.

5 Use of EUETS data in EU greenhouse inventories

The text in the sections below has been summarised from the 2010 National Inventory Report of the EU. It provides an overview of the way that ETS data can be used in the GHG inventories of the EU MSs, a summary of the way that ETS data is currently being used by MSs, and provides detailed examples of how the data have been used in three Member States.

5.1.1 Overview

The ETS generates an EU-27 data set on verified installation-specific CO_2 emissions for the sectors covered by the scheme. The ETS includes CO_2 emissions from energy industries and manufacturing industries, in particular combustion installations, mineral oil refineries, coke ovens, production and processing of ferrous metals, and mineral industries (cement, glass, lime, bricks and tiles, other ceramic materials) if the installations exceed certain capacity thresholds. In 2008 the scope of the EU ETS has been expanded to include petrochemical cracking installations, mineral wool production and carbon black production. At the moment, the greenhouse gases covered under the EU ETS are CO_2 (since 2005) and N_2O (since 2010). However, other greenhouse gases and activities will be included in the scope of the EU ETS from 2013 onwards. In July 2006 the Climate Change Committee adopted unanimously the revised Monitoring and Reporting Guidelines for the ETS. The new Guidelines entered into force on 1st January 2008.

5.1.2 How might EUETS data be able to improve the EU GHG inventory?

The EU inventory is composed of the sum of the GHG inventories of the Member States of the EU. The plant-specific emissions data reported by operators under the EUETS can be used in different ways for the purposes of the E GHG inventories:

1) Reported verified emissions can be directly used in the GHG inventory to report CO_2 emissions for a specific source category. This requires that the coverage of the respective ETS emissions is complete for the respective source category and that ETS activities and CRF source categories follow the same definitions. If ETS emissions are not complete, the emissions for the remaining part of the source category not covered by the EU ETS have to be calculated separately and added to the ETS emissions.
2) Emission factors (or other parameters such as oxidation factors) reported under the EUETS can be compared with emission factors used in the inventory and they can be harmonised if the EUETS provides improved information.
3) Activity data reported under the EUETS can be used directly for the GHG inventory, in particular for source categories where energy statistics face difficulties in disaggregating fuel consumption to specific subcategories, e.g. to specific industrial sectors.
4) Data from EUETS can be used for more general verification activities as part of national quality assurance (QA) activities without the direct use of emissions, activity data or emission factors.
5) Data from EUETS can improve completeness of the estimation of IPCC source categories when additional data for source categories become available from EUETS.
6) ETS data can improve the allocation of industrial combustion emissions to sub-categories under 1A2 Manufacturing Industries and Construction;
7) The comparison of the data sets can be used to improve the uncertainty estimation for the GHG inventories based on the ranges of data reported by installations.

5.1.3 *Extent of use of ETS data in the EU inventory*

Based on the information submitted in the national inventory reports (NIRs) in 2010 to the UNFCCC secretariat or the European Commission, 24 out of 27 Member States indicated that they used ETS data at least for QA/QC purposes (see Table 5-1). This is a higher share of Member States than in 2008, where a similar analysis showed that 22 Member States had used ETS data for inventory purposes. 14 Member States indicated to directly use the verified emissions reported by installations under the ETS. 15 Member States used ETS data to improve country-specific emission factors. 10 Member States reported that they used activity data (e.g. fuel use) provided under the ETS in the national inventory.

The NIR of Lithuania did not provide any information whether ETS data was used for inventory purposes. For these Member States it is unclear whether they checked data consistency in a systematic way. Luxembourg and Bulgaria did not provide an updated NIR 2009 during the preparation of the 2010 NIR.

The analysis did not report explicitly whether countries has been able to discriminate between combustion and process related emissions from industry where both types of emissions occur, such as the iron and steel sector.

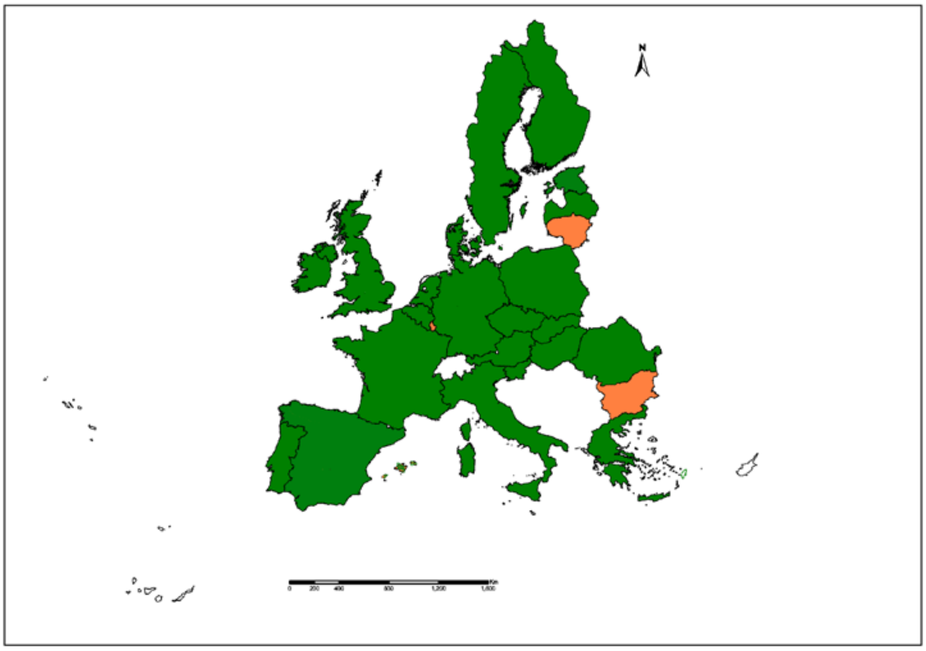
Table 5-1 Use of ETS data for the purposes of the national GHG inventory

Member State	Status of use of ETS data	Use of emissions	Use of Activity data	Use of emission factors	Use for quality assurance
Austria	Used	✓	✓	✓	✓
Belgium	Used	✓		✓	✓
Bulgaria	NIR 2010 not yet available				
Cyprus	Used			✓	✓
Czech Republic	Used	✓	✓	✓	✓
Denmark	Used	✓		✓	✓
Estonia	planned to use for verification in 2011 submission				✓
France	Used	✓			✓
Finland	Used	✓	✓	✓	✓
Germany	Used			✓	✓
Greece	Used	✓	✓	✓	
Hungary	Used	✓	✓	✓	✓
Ireland	Used	✓		✓	✓
Italy	NIR 2010 not yet available		✓	✓	✓
Latvia	Used	✓	✓	✓	✓
Lithuania	Not indicated				
Luxembourg	NIR 2010 not yet available				
Malta	Used	✓			✓
Netherlands	Used				✓
Poland	NIR 2010 not yet available	✓			
Portugal	Used	✓	✓	✓	✓
Romania	Used				✓
Slovakia	Used			✓	✓
Slovenia	Used		✓	✓	✓
Spain	Used				✓
Sweden	Used	✓	✓		✓
United Kingdom	Used	✓		✓	✓

Source: NIR submissions to UNFCCC 2009

Figure 5-1 shows the extent of ETS use in the EU. Green indicates the NIR provides information how ETS data was used for GHG inventory. Red indicates no information provided in NIR about whether ETS data was used. No NIR for Luxembourg was available during the preparation of EU 2010 NIR.

Figure 5-1 Use of ETS data for inventory purposes in the EU



The following assessment provides a detailed overview of the use of ETS data in the EU-15 Member States. The information is mainly based on the NIR, as well as on the assessment conducted for this report.

5.1.4 Use of ETS data for GHG inventories in specific countries

Three countries have been chosen to illustrate the use of ETS data in national GHG inventories: the two largest GHG emitters in Europe (Germany and France, with well developed national inventory systems), and Greece representing a less mature but developing GHG inventory. The authors of he EU NIR split the analysis into the use of energy, and industrial processes and the analysis they made is reproduced below.

Germany

General

The coverage of CO_2 emissions from ETS activities in relation to individual CRF source categories is not provided in the NIR.

In 2006 a research project compared ETS emissions and inventory emissions and developed allocation rules how the ETS emissions should be allocated to inventory categories. Then a formalized procedure was developed for the annual data exchange between ETS authority and the inventory system. ETS data are generally used for verification and QA purposes but not directly in the inventory. Emission factors from ETS data are also used. Activity data from ETS data are not used because these data are confidential and would decrease the transparency of the GHG inventory.

In the CRF table 1s1 (Energy) Germany reports an additional source category that includes the combustion emissions from source categories covered by the ETS (glass, cement and ceramics). This additional voluntary reporting considerably enhances the comparability of ETS emissions with inventory emissions at sectoral level.

Energy

The NIR generally indicates that ETS data are used for verification purposes. Both systems, the inventory and the ETS, refer to a list of “basic” CO_2 emission factors in the energy sector.

Industrial processes

- 2A1 Cement Production: EFs between inventory and ETS are largely consistent, deviation of 1%.

- 2A3 Limestone and dolomite use: ETS data is used for verification and QA.
- 2A7: Glass Production: emissions were compared with ETS emissions and found to be in agreement.

France

General

The coverage of CO_2 emissions from ETS activities in relation to individual CRF source categories is provided for some categories in the NIR:

- Glass Production: no complete coverage of ETS data.
- Bricks and Tiles Production: 51 out of 140 plants are covered by the ETS

France indicates in a general way that CO_2 emissions in the inventory are consistent with ETS emissions because they are based on the same data sources. In France plant-specific data is collected by the same entities from the same installations for both the EUETS and the GHG inventory and energy statistics and data is therefore consistent. Small deviations occur for the following reasons:

- The CO_2 emissions from blast furnace gas are allocated to the producer and could also be allocated to the user in different systems.
- Small installations with small emissions are not individually included in the estimation approach.
- The sectoral and source category definitions can be different.

For 2005, a total deviation of 0.5% between ETS emissions and inventory emissions has been estimated, with the largest deviations for iron and steel industry and manufacturing industries.

Energy

- 1A1 Energy industry: calculated emissions are verified with the emissions data reported under the ETS.
- 1B2a Petroleum refining: CO_2 emissions are declared by the plants under the EUETS.
- 1A1c Manufacture of solid fuels and other energy industries: the CO_2 emissions from ETS are used.

Industrial processes

- 2A1 Cement Production: France directly uses the emissions reported under the ETS.
- 2A2 Lime Production: ETS data are used for the inventory reporting.
- 2A5 Glass Production: ETS data are used for the inventory reporting. They are completed with the remaining glass production not covered by the ETS. For this part of the production national emission factors are used.
- 2A5 Bricks and Tiles Production: 51 out of 140 plants are covered by the ETS. The emissions from ETS plants are taken directly from the ETS reports. These emissions are complemented based on the remaining national production and emission factors taken from ETS reports.

Greece

General

The coverage of CO_2 emissions from ETS activities in relation to individual CRF source categories is not provided systematically, but the NIR from Greece indicated that all iron and steel plants are covered by the ETS.

Greece used AD and EF obtained from reporting under the ETS for the GHG inventory. In addition to the verified emissions provided for the period 2005-2007, data collected for the purposes of the national allocations plans for the ETS installations were collected for the period 2000-2006 and in some cases for the period 1990-2006 and this information was also used as a source for the inventory compilation. ETS data were used for 1A1, 1A2 and industrial processes.

Energy

- For the fuels refinery gas, petroleum coke and PKB/Patent fuels NCVs were obtained from verified reports from installations under the ETS. The ETS EF and AD were combined with remaining production and IPCC default EF to obtain complete emission estimates.

- The CO_2 emissions from the operation of flue gas desulphurization systems (limestone consumption in two power plants): data from verified installation ETS reports were used.
- 1A1a Public Electricity and Heat: Activity data of natural gas combustion were updated for the years 2005-2007 based on plant specific data, derived from verified ETS reports.
- 1A1b Petroleum Refining: Tier 2 methodology was used with EFs calculated based on plant specific data (ETS reports) and IPCC default EFs for the whole time series. CO_2 and N_2O emissions from catalytic cracking are included in this sub-source category, while CH_4 emissions are supposed to be included in Fugitive emissions from fuels.
- 1A1c Manufacture of Solid Fuels and Other Energy Industries: Data collected during the formulation of the NAP for the period 2005 – 2007 and verified ETS reports (for years 2005 - 2007) were used in this inventory, particular EFs. The allocation of the consumption into gas turbines and boilers as taken from ETS reports. The CO_2 EF of natural gas was estimated to comprise emissions from the processing of sour gas cleaning process among with the emissions from combustion. The EF for the processing of sour gas is based on ETS data.
- 1A2 Manufacturing Industries and Construction: ETS data were used for an improved distribution of fuel consumption to different technologies and activities. ETS data was used to improve completeness of subcategories in the inventory. The NIR provides detailed information on 1A2a Iron and Steel, 1A2 b Non-ferrous metals, 1A2c Chemicals, 1A2d Pulp and Paper, 1A2e Food Processing, Beverages and Tobacco and 1A2f Other. 1A2c Chemicals: The activity data of gaseous and liquid fuels were updated for the years 2005-2007, based on plant specific data, derived from verified ETS reports. Moreover, according to plant specific data of refineries, the amounts of NG and naptha used for hydrogen production were reallocated to 1.A.1.b sector.
- Energy consumption in Non metallic minerals is disaggregated into energy consumption for cement production (SNAP 030311), lime production (SNAP 030312), ceramics production (SNAP 030319) and glass production (SNAP 030105) according to verified ETS reports of years 2005 - 2008.
- Data on the non-energy consumption of fuels derive from the national energy balance. However, plant specific data derived from verified ETS reports and information provided by specific industries in Greece resulted to the improvement of reallocation of non-energy use fuels from the energy to the industrial processes sector: The non-energy use of natural gas for ammonia production has been reallocated in industrial processes sector, by using data from ETS reports and plant specific information.
- Solid fuels consumption in the ferroalloys production industry is included (in the national energy balance) in the solid fuels consumption of the non-ferrous metals sector. However, by using data from ETS reports and plant specific information, emissions from solid fuels for ferroalloys production are reallocated to the industrial processes sector, as from this submission.

Industrial processes

- CO_2 emissions from the majority of mineral and metal industries are estimated on the basis of country-specific emission factors. These emission factors derive of plant specific activity and emission data in the context of the EU ETS. Plant specific information has been collected through questionnaires for the formulation of the NAP (years 1990-2003) and verified reports under the EU ETS.
- 2A1 Cement Production: For the years 2005-2007 detailed data have been accessed via the verified ETS reports of the plants. These data refer to the quantities of carbonate raw material ($CaCO_3$, $MgCO_3$) used for the production of clinker.
- 2A1 Lime Production: The emissions are estimated making use of plant-specific data provided by the verified reports of the plants under the ETS. According to data received by the ETS, it seems that the main lime industries have significantly increased limestone consumption in 2007, which explains the increasing trend from 2005 to 2007.
- 2A3 Limestone and dolomite use: Steel production: Data are generally plant specific, deriving from the EU ETS verified reporting of the plants (for the years 2005-2008); Ceramics production: Carbonates consumption data (in the context of the ETS reports) have been used to estimate emissions in the years 2005-2008. Activity data refer to $CaCO_3$ and $MgCO_3$ consumption. SO_2 scrubbing: The operation of flue gas desulphurization systems in Greece started in 2000. The estimation of emissions is based on data collected during the formulation of the NAP for the period 2005 – 2007. For years 2005-2008 data from verified installation ETS reports were used.

- 2A7 Glass Production: Activity data for the period 2001 – 2004 were collected (through questionnaires developed according to the guidelines described in the Commission Decision 2004/156/EC) in the framework of the formulation of the NAP for the period 2005 – 2007, according to the EU Directive 2003/87/EC. The detailed data of 2005-2007 by the verified EU ETS reports have led to the need for recalculation of the time-series in order to ensure consistency.
- 2A7 Ceramics Production: Carbonates consumption data (in the context of the ETS reports) have been used for 2006 and 2007 emissions estimation.
- 2B1 Ammonia Production: The non-energy use of natural gas for ammonia production is reallocated in industrial processes sector as from the 2009 submission, by using data from ETS reports and plant specific information.
- 2C1 Iron and Steel: Data are generally plant specific, deriving from the EU ETS verified reporting of the plants (for the years 2005-2007) and the reporting performed for the NAP formulation in the previous years. Activity data and EF for 2005-2007 are plant specific and are based on the verified reports under the EU ETS context.
- 2C2 Ferroalloys Production and primary aluminium production: Activity data for 2005-2007 derive of the verified reports of the industry under the EU ETS.

5.1.5 Summary

EUETS data can benefit the EU GHG inventories in a variety of ways, including:

- Reported verified emissions can be directly used in the GHG inventory to report CO_2 emissions for a specific source category.
- Emission factors and other parameters such as oxidation factors can be compared with emission factors used in an inventory and they can be harmonised if appropriate.
- Activity data reported under the EUETS can be used directly for the GHG inventory, in particular for source categories where energy statistics face difficulties in disaggregating fuel consumption to specific subcategories.
- Data from EUETS can improve completeness of the estimation of IPCC source categories.

EUETS data are widely used in the GHG inventories of EU Member States:

- Nearly all Member States use the ETS for quality control and verification purposes. Often the emissions reported in the ETS are compared with emissions reported in the GHG inventory of a MS.
- Both mature and more recent GHG inventories were able to make use of EUETS data.
- Many MSs use EUETS emissions in their GHG inventory, and some use activity data and emission factors.
- Some countries have completed specific studies to examine the feasibility of using ETS data in GHG inventories prior to ETS data being used.
- Collection of plant specific data by the same entities compiling the GHG inventory, the ETS and national energy statistics could promote internal consistency and efficiency.
- Germany reports an additional source category that includes the combustion emissions from source categories covered by the ETS (glass, cement and ceramics). This additional voluntary reporting considerably enhances the comparability of ETS emissions with inventory emissions at sectoral level.
- France reports a very close agreement between the ETS emissions and estimates of GHG emissions. It is likely that close agreement is because the plant specific data is collected by the same entities compiling the GHG inventory, the ETS and national energy statistics.
- There are some problems discriminating between combustion and process emissions from ETS returns.
- Detailed ETS data has been helpful to provide information about the specific uses of fuels, for example, reallocating the of non-energy use fuels from the energy to the industrial processes sector.
- There was no information in the EU NIR about how and if the Tier associated with ETS data had been used to judge the suitability of the data used.

6 Questions for discussion

This paper has raised a number of questions that would be useful to consider, particularly if more detailed guidance is written by the IPCC about integrating ETS data into a GHG inventory

- Securing access to ETS data. What are suitable approaches to securing reliable access to ETS data, whilst maintaining commercial confidentiality?
  - Developments to improve usefulness of EUETS data within GHG inventory. EUETS data management decisions to simplify the data allocation issues could be considered, such as:
    - Harmonising activities. Installations could be allocated to a harmonised list of activities, aligned with IPCC sectors.
    - Harmonising fuel names. Operators could allocate fuels to a harmonised, limited list of fuel types that can then be more easily / consistently be allocated to IPCC fuel types. This would supplement, not replace, the existing ETS reporting.
      - e.g. fuel use, NCVs and emissions are reported from fuels which cannot be easily identified. This is a particular problems for petroleum-derived fuels and from non-standard fuels such as process gases, refinery off-gases, flared fuels etc where fuel quality is expected to be variable. (i.e. non-refined, non-processed fuels, where the specification of the fuel quality is not closely defined)
    - Clarity of reporting. Improve disaggregation of activities to report emissions from specific activities, and from the use of biomass.
      - e.g. power stations – allocate emissions from fuel use (by fuel), from biomass and for other sources such as flue gas desulphurisation
- More research to investigate EUETS data quality management is needed, for example, through cross-sectoral, cross-Member State fuel data analysis to identify outliers, system inconsistencies within a country, between sectors or between countries. It is not appropriate to use all ETS data in a GHG inventory since some of these data may be of lower quality that the data already in the GHG inventory. This raises the questions of whether it is possible to devise guidance on the accuracy and / or uncertainty must be associated with data with before these ETS data can be used in a GHG inventory?
- Would new IPCC guidance on "good practice" use of ETS data be appropriate?
  - Guidance on how to integrate new ETS data into existing GHG inventories to minimise impacts on time-series consistency.
  - Best practice guidance on data quality checking, identification of outliers, resolution of activity data discrepancies
  - Best practice guidance on when to use EUETS data to either (i) change the national energy statistics total, or (ii) change the sector allocation of the existing total national energy statistics.
  - Preparing the guidance for future changes driven by a lower carbon economy. The current status may not persist, e.g. the development of more regionally disaggregated electricity generation will mean there will be challenges to track fuel use and fuel quality as countries may move to more to a smaller-scale lower-carbon generation infrastructure.

7 Concluding remarks

This analysis has demonstrated that emissions data given in the UK GHG inventory are often broadly consistent with emissions data given in regulators' inventories, in the CITL (reporting verified emissions from the EUETS), and in other data sets. In some cases where there are differences, we are able to identify reasons why these differences exist. The UK is making use of some detailed EUETS data in its inventory, such as carbon emission factors for fuels used in key sources (coal and gas used in power stations) and for fuels whose composition is variable (some fuels used in refineries).

Further investigation would be needed to completely understand issues such as the difference in scope between processes for the purpose of inclusion in the regulators' inventories compared with the scope of those same processes when covered by the EU ETS.

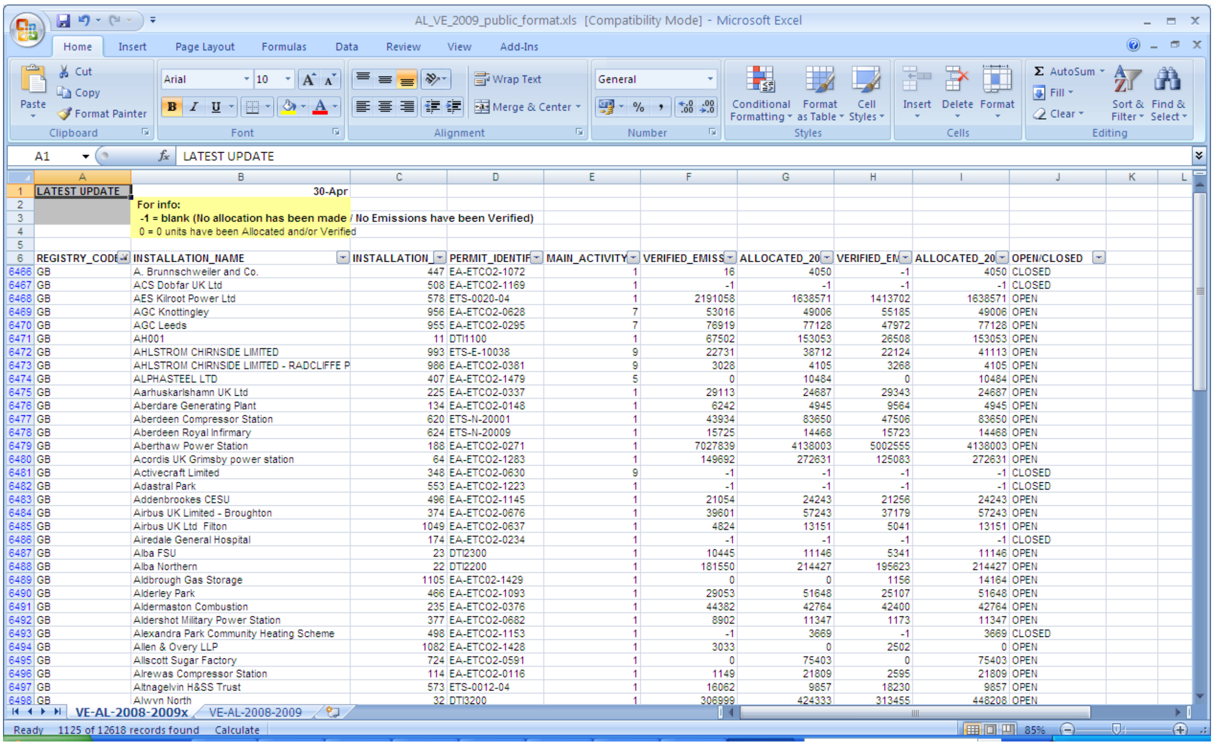
In the European Community, good use is being made of data from the EUETS in the GHG inventories of many countries.

We suggest that the ETS is a valuable source of data, but countries need to carefully investigate the relationship between emissions reported in the ETS and in other related data sets before ETS data can be used directly in GHG inventories. An annual repetition of the detailed numerical analysis is not considered essential once the key features are understood, but would probably be useful on a periodic basis, perhaps every 3 years.

Annex 1

Extract of UK verified emissions for 2008-2009, and allocations for 2008-2009, to illustrate the level of verified emission data that is publically available. Taken from the spreadsheet <AL_VE_2009_public_format.xls> available on the Europe web site (run by the European Commission) at:

http://ec.europa.eu/environment/climat/emission/citl_en_phase_ii.htm#reports



LATEST UPDATE 30-Apr

For info:
-1 = blank (No allocation has been made / No Emissions have been Verified)
0 = 0 units have been Allocated and/or Verified

	REGISTRY_CODE	INSTALLATION_NAME	INSTALLATION_	PERMIT_IDENTIF	MAIN_ACTIVITY	VERIFIED_EMISS	ALLOCATED_20	VERIFIED_EM	ALLOCATED_20	OPEN/CLOSED
6466	GB	A. Brunnschweiler and Co.	447	EA-ETCO2-1072	1	16	4050	-1	4050	CLOSED
6467	GB	ACS Dobfar UK Ltd	508	EA-ETCO2-1169	1	-1	-1	-1	-1	CLOSED
6468	GB	AES Kilroot Power Ltd	578	ETS-0020-04	1	2191058	1638571	1413702	1638571	OPEN
6469	GB	AGC Knottingley	956	EA-ETCO2-0628	7	53016	49006	55185	49006	OPEN
6470	GB	AGC Leeds	955	EA-ETCO2-0295	7	76919	77128	47972	77128	OPEN
6471	GB	AH001	11	DTI1100	1	67502	153053	26508	153053	OPEN
6472	GB	AHLSTROM CHIRNSIDE LIMITED	993	ETS-E-10038	9	22731	38712	22124	41113	OPEN
6473	GB	AHLSTROM CHIRNSIDE LIMITED - RADCLIFFE P	986	EA-ETCO2-0381	9	3028	4105	3268	4105	OPEN
6474	GB	ALPHASTEEL LTD	407	EA-ETCO2-1479	5	0	10484	0	10484	OPEN
6475	GB	Aarhuskarlshamn UK Ltd	225	EA-ETCO2-0337	1	29113	24687	29343	24687	OPEN
6476	GB	Aberdare Generating Plant	134	EA-ETCO2-0148	1	6242	4945	9564	4945	OPEN
6477	GB	Aberdeen Compressor Station	620	ETS-N-20001	1	43934	83650	47506	83650	OPEN
6478	GB	Aberdeen Royal Infirmary	624	ETS-N-20009	1	15725	14468	15723	14468	OPEN
6479	GB	Aberthaw Power Station	188	EA-ETCO2-0271	1	7027839	4138003	5002555	4138003	OPEN
6480	GB	Acordis UK Grimsby power station	64	EA-ETCO2-1283	1	149692	272631	125083	272631	OPEN
6481	GB	Activecraft Limited	348	EA-ETCO2-0630	9	-1	-1	-1	-1	CLOSED
6482	GB	Adastral Park	553	EA-ETCO2-1223	1	-1	-1	-1	-1	CLOSED
6483	GB	Addenbrookes CESU	496	EA-ETCO2-1145	1	21054	24243	21256	24243	OPEN
6484	GB	Airbus UK Limited - Broughton	374	EA-ETCO2-0676	1	39601	57243	37179	57243	OPEN
6485	GB	Airbus UK Ltd Filton	1049	EA-ETCO2-0637	1	4824	13151	5041	13151	OPEN
6486	GB	Airedale General Hospital	174	EA-ETCO2-0234	1	-1	-1	-1	-1	CLOSED
6487	GB	Alba FSU	23	DTI2300	1	10445	11146	5341	11146	OPEN
6488	GB	Alba Northern	22	DTI2200	1	181550	214427	195623	214427	OPEN
6489	GB	Aldbrough Gas Storage	1105	EA-ETC02-1429	1	0	0	1156	14164	OPEN
6490	GB	Alderley Park	466	EA-ETCO2-1093	1	29053	51648	25107	51648	OPEN
6491	GB	Aldermaston Combustion	235	EA-ETCO2-0376	1	44382	42764	42400	42764	OPEN
6492	GB	Aldershot Military Power Station	377	EA-ETCO2-0682	1	8902	11347	1173	11347	OPEN
6493	GB	Alexandra Park Community Heating Scheme	498	EA-ETCO2-1153	1	-1	3669	-1	3669	CLOSED
6494	GB	Allen & Overy LLP	1082	EA-ETCO2-1428	1	3033	0	2502	0	OPEN
6495	GB	Allscott Sugar Factory	724	EA-ETCO2-0591	1	0	75403	0	75403	OPEN
6496	GB	Alrewas Compressor Station	114	EA-ETCO2-0116	1	1149	21809	2595	21809	OPEN
6497	GB	Altnagelvin H&SS Trust	573	ETS-0012-04	1	16062	9857	18230	9857	OPEN
6498	GB	Alwyn North	32	DTI3200	1	306999	424333	313455	448208	OPEN

Annex 2

Example of the detailed returns that the UK participants of the ETS make to the UK Environment Agency. The Environment Agency is the regulatory of the ETS in the UK. These data are commercially confidential, and emissions and most data in this return has been anonomised and set to a value of 1.

PGB1

B1 Combustion emissions data (M&RG Section 11.3)

Please complete the following pages for each Schedule 1 combustion process within your installation. Emissions occurring from different sources within a single installation belonging to the same type of activity may be reported in an aggregate manner for the type of activity provided that the emission factors and the oxidation factors are identical.

B1.1 Calculation of carbon dioxide emissions from fossil fuel combustion (for M&RG Annex II activities)

Relevant Row ID in Table A 2.1:	1
Type of Schedule 1 activity:	E1 Combustion
Description of activity:	Various boilers and furnaces (heaters) providing heat/energy to the oil refining process. Flares.

Please complete the following boxes using one box for each fuel associated with the activity stated above.

*** NCV - Net Calorific value**

Type of fuel:	RFG		
Sources included	Various		
Parameter	**Units**	**Data**	**Tier applied**
Activity data (mass/vol.)	m3	1	Tier 4a
(NCV)*	TJ/m3	1	Tier 3
Emission factor	tCO2/TJ	1	Tier 3
Oxidation factor	no units	0.995	Tier 1
Emissions	tCO_2	1	

Type of fuel:	Flare1		
Sources included	#1 Flare		
Parameter	**Units**	**Data**	**Tier applied**
Activity data (mass/vol.)	m3	1	Tier 2
(NCV)*			
Emission factor	tCO2/m3	1	Tier 1
Oxidation factor	no units	0.995	Tier 1
Emissions	tCO_2	1	

Type of fuel:	NG		
Sources included	GT706, GT711-4		
Parameter	**Units**	**Data**	**Tier applied**
Activity data (mass/vol.)	m3	1	Tier 4a
(NCV)*	TJ/m3	1	Tier 2
Emission factor	tCO2/TJ	1	Tier 2a
Oxidation factor	no units	0.995	Tier 1
Emissions	tCO_2	0.995	

Type of fuel:	Flare3		
Sources			
Parameter	**Units**	**Data**	**Tier applied**
Activity data (mass/vol.)	m3	1	Tier 2
(NCV)*			
Emission factor	tCO2/m3	1	Tier 1
Oxidation factor	no units	0.995	Tier 1
Emissions	tCO_2	0.995	

Type of fuel:	SG		
Sources included	GT711-4		
Parameter	**Units**	**Data**	**Tier applied**
Activity data (mass/vol.)	tonnes	1	Tier 4a
(NCV)*	TJ/tonne	1	Tier 2
Emission factor	tCO2/TJ	1	Tier 2a
Oxidation factor	no units	0.995	Tier 1
Emissions	tCO_2	0.995	

Type of fuel:	VG1		
Sources included	H4101		
Parameter	**Units**	**Data**	**Tier applied**
Activity data (mass/vol.)	tonnes	1	No Tier
(NCV)*	TJ/tonne	1	Tier 2
Emission factor	tCO2/TJ	1	Tier 2a
Oxidation factor	no units	0.995	Tier 1
Emissions	tCO_2	0.995	

Type of fuel:	Diesel		
Sources included	EDG-709/710/711/801, DFP, OH, COMP		
Parameter	**Units**	**Data**	**Tier applied**
Activity data (mass/vol.)	tonnes	1	No Tier
(NCV)*	TJ/tonne	1	Tier 2
Emission factor	tCO2/TJ	1	Tier 2a
Oxidation factor	no units	0.995	Tier 1
Emissions	tCO_2	1	

Type of fuel:	VG2		
Sources included	H1102		
Parameter	**Units**	**Data**	**Tier applied**
Activity data (mass/vol.)	tonnes	1	Tier 3a
(NCV)*	TJ/tonne	1	Tier 2
Emission factor	tCO2/TJ	1	Tier 2a
Oxidation factor	no units	0.995	Tier 1
Emissions	tCO_2	1	

Annex 3

Example of the detailed ETS data that the UK GHG inventory team is now able to access. The data is supplied from database that the UK Environment Agency maintains. These data are commercially confidential and data has been anonomised.

AppID	ReportingYear	ActivityID	FuelID	FuelType	SourcesIncluded	ActivityUnit	ActivityData	ActivityTier	NCVUnit	NCVData	NCVTier	EFUnit	EFData	EFTier	OxFactorData	OxFactorTier	CombustionEmissions	WasteCat	IEA
	2007	1	1	RFG (OPG): F1 (major)	S1-S10 inclusive, S47	tonnes	148332.023	Tier 4a	TJ/tonne	0.051186	Tier 3	tCO2/t	1.303954	Tier 3	0.995	Tier 1	218818.9626		
	2007	1	2	RFG (OPG): F3 (major)	S36 & S37	tonnes	74010.46714	Tier 4a	TJ/tonne	0.051501	Tier 3	tCO2/t	1.294011	Tier 3	0.995	Tier 1	108347.4423		
	2007	1	3	RFG (OPG): F5 (major)	S40	tonnes	32765.1604	Tier 4a	TJ/tonne	0.043339	Tier 3	tCO2/t	1.238423	Tier 3	0.995	Tier 1	45905.9458		
	2007	1	4	Fuel Oil: F7 (major)	S22,S23,S28	tonnes	64607.9733	Tier 3a	TJ/tonne	0.040322	Tier 3	tCO2/t	1.522725	Tier 3	0.995	Tier 1	111300.0218		
	2007	1	5	Flare F10 (minor)	S41	tonnes	26269.23526	Tier 1	TJ/tonne	0.04875	Tier 2	tCO2/TJ	1.274472	Tier 2	0.995	Tier 1	37876.11951		
	2007	1	6	RFG (OPG): F1 (De Minimis)	S38 & S58-68 inclusive	tonnes	7205.561792	No Tier	TJ/tonne	0.051172	Tier 3	tCO2/t	1.304572	Tier 3	0.995	Tier 1	10634.65986		
	2007	1	7	RFG (OPG): F3 (De Minimis)	S81 & S82	tonnes	2736.665494	No Tier	TJ/tonne	0.0515	Tier 3	tCO2/t	1.294437	Tier 3	0.995	Tier 1	4007.655431		
	2007	1	8	GO: F12 (De Minimis)	S43, S44 & S55	tonnes	459.0479326	No Tier	TJ/tonne	0.0434	Tier 2	tCO2/t	1.51844	Tier 2a	0.995	Tier 1	788.5755405		
	2007	1	9	RFG (OPG): F2 (major)	S11-S21 inclusive	tonnes	142673.909	Tier 4a	TJ/tonne	0.048064	Tier 3	tCO2/t	1.257598	Tier 3	0.995	Tier 1	202989.7431		
	2007	1	10	RFG (OPG): F4 (major)	S22-S24 & S26-S30 inclusive, S48	tonnes	226348.8885	Tier 4a	TJ/tonne	0.04334	Tier 3	tCO2/t	1.227377	Tier 3	0.995	Tier 1	314299.8167		
	2007	1	11	Fuel Oil: F6 (major)	S1,S36	tonnes	179287.7307	Tier 4a	TJ/tonne	0.040363	Tier 3	tCO2/t	1.537078	Tier 3	0.995	Tier 1	311769.8771		
	2007	1	12	Natural Gas F9 (major)	S39,S40	tonnes	181292.7382	Tier 4a	TJ/tonne	0.046536	Tier 3	tCO2/t	1.256929	Tier 3	0.995	Tier 1	257797.6337		
	2007	1	13	Flare F11 (minor)	S42	tonnes	47106.05252	Tier 1	TJ/tonne	0.035249	Tier 2	tCO2/t	1.086765	Tier 2	0.995	Tier 1	57916.16495		
	2007	1	14	RFG (OPG): F2 (De Minimis)	S69-80 inclusive	tonnes	2472.533571	No Tier	TJ/tonne	0.048106	Tier 3	tCO2/t	1.259136	Tier 3	0.995	Tier 1	3522.105443		
	2007	1	15	RFG (OPG): F4 (De Minimis)	S50,S83,S84	tonnes	1569.279963	No Tier	TJ/tonne	0.043228	Tier 3	tCO2/t	1.225692	Tier 3	0.995	Tier 1	2176.052979		
	2007	1	16	F13 (De Minimis)	S49 (VDU-2 Offgas)	tonnes	8925.438353	No Tier	TJ/tonne	0.048165	No Tier	tCO2/t	1.033327	No Tier	0.995	No Tier	10434.09423		

The use of facility-specific emission factor data in Australia's national inventory

Rob Sturgiss

Director

National Inventory Team

Department of Climate Change and Energy Efficiency

Australian Government

Invited Background Paper to the IPCC Experts Meeting,

Sydney, Australia, 9 – 11 August 2010

Summary

The Australian national inventory is in the process of transitioning from the use of tier 2 methods in which representative country-specific emission factors are applied in the emission calculations for all facilities within a sector to the use of a set of tier 3 methods which utilises newly available information on facility-specific emission factors.

The new information has been derived from the recent introduction of a mandatory emissions reporting system (the National Greenhouse and Energy Reporting system – (NGERs)). The implementation of the NGER system involved all major companies in Australia and has constituted a substantial allocation of resources and effort by private operators towards emissions measurement in Australia.

The new information is yet to be incorporated into the national inventory. Guidance on the use of facility or plant-specific information in national inventories is included in the 2006 IPCC Guidelines, which address the use of tier 3 methods for the Energy, IP and Waste sectors. However, the Guidelines do not assume that all plant-specific information will be used in an inventory as guidance is also provided on the use of plant-specific information as a QC tool to test the reasonableness of tier 2 national emission factors. Given these two broad scenarios, some interpretation of the Guidelines is required in the consideration of how to best use the new plant-specific information in the national inventory.

With future Australian inventories in mind, a decision tool has been developed to provide a framework for a consistent, coherent use of facility-specific information across all targeted sectors of the Australian inventory.

Given the nature of the IPCC guidance in this area, and the provision for the use of expert judgements for many decisions, IPCC workshops and conferences may have a useful role to perform in assisting inventory compilers and other experts in developing their understanding of how to improve national inventories through the use of plant-specific data.

Australia's national inventory's use of plant-specific tier 3 methods

Australia's national inventory currently uses mainly tier 2 methods for energy, industrial processes and waste. For any source, the tier 2 methods commonly apply a representative country-specific factor to the national population of facilities that generate the emissions for the source. Two exceptions are fuels consumed for the purpose of electricity production and fugitive emissions from underground coal mines where a tier 3 method is already in place (these two sources constitute around 50% of NGER emissions).

The national inventory is in the process of transitioning from the use of tier 2 methods to the use of a set of tier 3 methods which utilise newly available information on facility-specific data (mainly emission factors based on carbon content of fuels). The adoption of tier 3 methods is especially valuable for fuels where the carbon content varies appreciably across the economy – this is particularly the case for coal but also natural gas. Tier 3 methods are less important for relatively homogenous fuels like petroleum based products.

National Greenhouse and Energy Reporting System (NGERs)

The catalyst for the transition to tier 3 methods has been the implementation of the National Greenhouse and Energy Reporting Act 2007. The Act provides for mandatory reporting of emissions (and energy) data by all companies that breach certain thresholds and represents a significant enhancement if Australia's national inventory systems.

The first reporting period under the NGER Act related to the Australian financial year 2008-09 while the first reports submitted by companies were received in October 2009. Consequently, given these timeframes, the data received under NGERs is yet to be incorporated into an Australian inventory submitted under the UNFCCC.

The features of the NGER reporting system include:

- broad coverage of emissions sources, including IPCC sources energy (fuel combustion), energy (fugitive), industrial processes and waste;
- a relatively low reporting thresholds that relates to facilities at 25kt of emissions (including scope 2 emissions) and for companies at 50kt of emissions;
- like the EU ETS and the US mandatory GHG reporting rule, reporters are able to choose between a number of methods in certain circumstances and in particular, reporters may:
  - use own measurements of carbon content based on the application of Australian and international standards ; or
  - use country-specific default emission factors; or
  - undertake direct monitoring of emissions;
- integration of the facility methods with the national inventory - the default factors used are country-specific factors taken directly from the national inventory;
- mandatory use of higher order emission estimation methods for the electricity generation, underground coal mines and PFC emissions from aluminium smelters; and
- strong compliance provisions exist with powers of audit provided for the Regulator while significant penalties exist for breaches.

More detail is provided in the Appendix.

As with any inventory, the decision to invest in enhanced use of measurement data required a balance to be struck between the costs and benefits of the additional measurement effort. In practice, in Australia, direct monitoring of emissions only occurs in underground coal mines. For fuel combustion and, in particular, fuel combustion for electricity generation, measurement of the carbon content of the fuel is normally undertaken for commercial or existing regulatory reasons.

The provision for reporters to be able to choose their estimation method reflected in part international practice but also recognition that the costs of measurement were uncertain for many sources. The interpretation of how to use data collected given this provision in the national inventory constitutes the principal discussion point in this paper. Nonetheless, the first year of implementation of NGERs provoked a massive investment in emissions measurement activity across the economy and the data collected represents a significant enhancement of our understanding of the driving forces behind actual emissions estimates in Australia.

The operation of this provision could be considered temporary in nature as it is intended for the system to gradually move to more comprehensive use of higher order emissions estimation methods over time.

What new information does the reported NGERs data contain? Data received under NGERs

Considerable facility-specific data has been received under NGERs for the carbon content of black coal, brown coal, natural gas, coal seam methane fuel combustion. Smaller samples were collected for other fuels.

In particular, in the first reporting year under NGERs over 120 facilities reported the consumption of black coal with associated emissions of over 131 Mt of CO_2. Thirty-one of these facilities reported using methods 2 or 3 accounting for around 124 Mt of CO_2. The majority of these facilities are electricity generators who are required to use method 2, 3 or 4 under NGER$_S$. Eighty-nine facilities reported the consumption of black coal using method 1. This represented only 7.3 Mt of CO_2 (less than 6% of reported emissions from this fuel). The majority of these emissions are reported by the 16 facilities who reported greater than 1 PJ of coal consumption (around 100,000 tonnes of CO_2 emissions). Most method 1 coal reporters consume significantly less coal: some reported less than 10 tonnes of consumption.

Similarly, data on facility-specific emission factors representing just under 100% of emissions from brown coal was obtained.

Analysis of the collected data generally showed strong agreement with existing tier 2 parameters. For example, for black coal, the average emission factor for the data collected from facilities accounting for over 90% of emissions from black coal (other than that used to produce coke) was 90.4 tonnes of carbon dioxide per gigajoule of black coal. The mean of the NGERs sample was not significantly different to the NGERs default emission factor of 88.2 tonnes of carbon dioxide per gigajoule of black coal. For brown coal, the average emission factor of this group of NGER reporters was 92.9 tonnes of carbon dioxide per gigajoule of brown coal. The NGER default emission factor was 92.7 tonnes of carbon dioxide per gigajoule of brown coal.

Use of the NGER data in the inventory

The data collected under NGERs represents a significant advance in the information available about the characteristics of emissions at plant level in Australia.

How should the data be utilised within the inventory?

The major decisions concern whether the plant specific data should be used directly in the inventory – or not. That is, should the NGER EF data be used directly in the inventory - a tier 3 method - or simply used for quality control?

In cases where plant specific data are not available for the complete source then an additional question arises as to how the NGER EF data should be used in relation to the uncovered portion of a source for which no facility-specific emission factor data is available. The true emission factor for facilities in the uncovered portion of a source is unknown and, therefore, a representative country-specific emission factor would need to be applied to these facilities.

Logically, three possibilities exist as to how the NGER data might inform the selection of a representative country-specific emission factor for the uncovered portion of the source:

1) the NGER data is valid and demonstrates that the existing tier 2 country-specific emission factor used for facilities in the uncovered portion of the source should be revised;
2) the NGER data is valid and confirms that the existing tier 2 country-specific emission factor is appropriate to continue to be applied to facilities in the uncovered portion of the source; or
3) the NGER data is not valid, and should not be used to assess the country-specific factor for the inventory.

Treatment of the use of plant specific data under the 2006 IPCC Guidelines

The 2006 IPCC Guidelines provide for a range of possibilities for the use of plant specific data.

Option 1: measured plant specific data used as a QC tool for the existing parameters in the tier 2 method

The 2006 IPCC Guidelines indicate in Volume 1 that plant specific data may be used for quality control purposes.

> *Compare country-specific factors with site-specific or plant-specific factors. For example, if there are emission factors available for a few plants (but not enough to support a bottom up approach) these plant specific factors ....provides an indication of both the reasonableness of the country specific factor and its representativeness.*

IPCC 2006 Vol 1 6.13

Option 2: measured plant specific data used as a tier 3 method

The 2006 IPCC Guidelines indicate in Volume 1 and in Volume 2, the Energy volume, that tier 3 methods can be deployed where there is complete coverage of plant specific data, such as, in Australia's case, in the electricity sector (see *IPCC 2006 Volume 2, 1.9)*.

Option 3: measured plant-specific data used in a tier 2 /3 mixed method

While complete coverage occurs for some sources, the more common situation is likely to be covered by a mix of data – option 3 – in which case the implementation of a mixed tier 2 /3 method is provided for. The decision tree in the Energy volume indicates the following decision making path for the use of plant specific (emission factor) data:

1) Are emission measurements available (with satisfactory QC)?
2) If yes then, are all single sources in the source category measured?
3) If no, then are country-specific EFs available for the unmeasured part of the key category?
4) If yes, then use a tier 2 / 3 mix.

IPCC 2006 Volume 2, 1.9 (paraphrased)

In addition, according to Volume 1 of the 2006 IPCC Guidelines, where plant specific data is available there are many situations where it should be used and that if a portion of the sector is not covered by available plant specific data then a country-specific factor should be applied to that portion.

> *When data do not fully represent the whole country, eg measurements for 3 out of 10 plants, then the data can still be used but needs to be combined with other data to calculate a national estimate.*
>
> *IPCC 2006 Volume 1, 2.10*

> *In these cases, expert judgement or the combination of these data with other datasets can be used.*
>
> *IPCC 2006 Volume1, 2.10*

While some general principles could be considered to implicitly underpin these statements there is no clear description in the Guidelines as to when option 1 or when option 3 should be applied. Rather, the Guidelines presume that expert judgement will be important in resolving decisions in relation to the application of the available options (also see below).

Importance of expert judgement

The 2006 IPCC Guidelines indicate that statistical principles should be taken into account when making judgements about how plant specific data should be used in the national inventory but that, equally, the decision making process as to how the plant specific data should be used ultimately involves considerable expert judgement.

> *When considering using measurement data it is good practice to check whether it covers a representative sample – ie that is typical of a reasonable proportion of the whole category*
>
> *IPCC 2006 Volume 1, 2.9*

> *A degree of judgement is required even when applying classical statistical techniques since one must judge whether the data are a representative sample. Interpretation is especially needed for data sets that are small, highly skewed or incomplete*
>
> *IPCC 2006 Volume 1, 2.6.*

> *Expert judgement on methodological choice and choice of input data to use is ultimately the basis of all inventory development.*
>
> *IPCC 2006 Volume 1, 2.6*

The implicit assumption behind the first excerpt from the IPCC guidelines indicates that the compiler is employing a statistical model to determine the country-specific factor for the residual portion of the sector where there are no measurements. Available plant specific data is to be assessed as to whether it would constitute a representative sample such that the characteristics of the sample may be extended to the portion of the sector for which measured plant specific data are not available. It follows from the second and third quotes that expert judgement is critical to the assessment of the representativeness of the available data.

If the available plant specific data do not pass the experts' tests of representativeness, what then?

In the case of any country, like Australia, in the process of transition from tier 2 to tier 3, the country-specific factor is already understood from the application of the existing tier 2 model. Consequently it is not unreasonable to conclude that the existing country-specific factor from the tier 2 model should continue to be used for the uncovered portion of the sector in this case.

Other possibilities might exist.

To sum up, the specific IPCC guidance in relation to the use of plant specific data do not seem to be prescriptive but, rather, presume that expert judgement will be important in resolving decisions in relation to the application of the data.

Decision tool to guide consistent application of decisions based on available information on the sample of facility-specific data

Given the broad nature of the IPCC guidance in this field, Australia has developed an approach to the use of plant specific data that is consistent with the IPCC guidelines and which attempts to provide a more explicit framework for the consistent determination as to how these data are used within the inventory.

With the preparation of Australia's future inventories in mind, the framework incorporates a decision tree to guide decision making to encourage consistent and coherent use of plant specific data throughout the inventory (see figure 1). In particular, conditions have been established that should be satisfied before plant specific data is incorporated into the national inventory.

These conditions include:

1) the sample of the population reporting plant specific data must be significant – both absolutely and relative to the overall population (the IPCC Guidelines refer to a 'reasonable proportion');
2) the sample must be representative; and
3) the sample must be approximately normally distributed and homogenous.

Plant specific data are used to revise the tier 2 country-specific emission factor for the portion of the inventory with no measurement data available when the conditions (1) – (3) above are satisfied while also taking into account whether: (4) the mean of the sample of plant specific data is significantly different to the country-specific tier 2 factor.

If these conditions hold, then the NGER EF data will be used a) for those plants reporting measured emission factors and b) to construct an NGER determined emission factor that is applied to all facilities for which there is no information available in relation to their actual plant-specific factor (the uncovered portion of the source).

If conditions (1) – (3) hold but (4) does not, then the NGER data is taken to be valid for those plants reporting data and, in relation to the unmeasured portion of the source, to have confirmed the pre-existing value of the country-specific emission factor. In this case, the pre-existing representative country-specific emission factor will be maintained for those facilities where no information is available on facility-specific factors.

If conditions (1) – (3) do not hold, further information is required to decide how the plant specific data should be used.

What if condition (1) is not maintained? – ie what if the sample of NGER EF data is not sufficiently large?

In this case, NGER data is taken to be insufficient to justify re-estimation of the country-specific emission factor for any part of the whole population. The pre-existing representative country-specific emission factor will be maintained for all facilities – ie the inventory will maintain a tier 2 method. The NGERs EF data will not be used in the inventory directly but will be used as a QC tool to check the reasonableness of the country-specific factor.

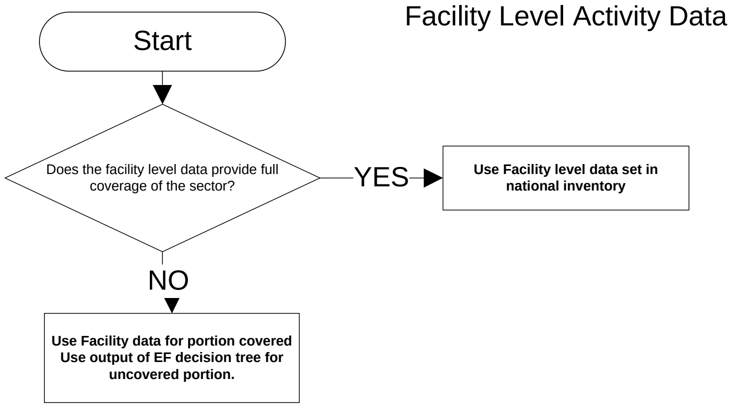
What if condition (2) is not maintained? – ie what if the sample is not representative?

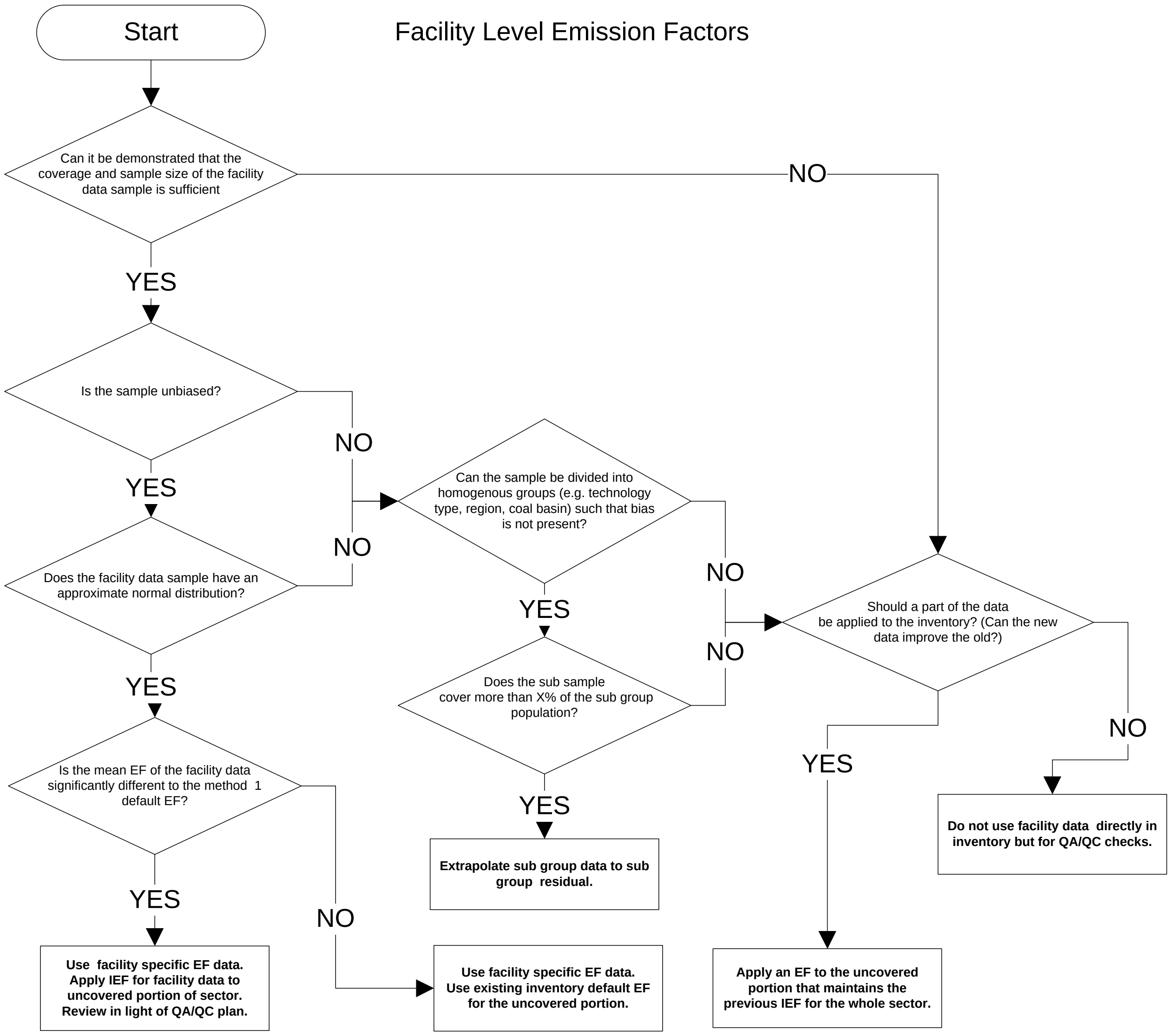
Under NGERs – like the EU ETS or the US EPA mandatory reporting rule – reporters are sometimes offered the opportunity to select their method of emission estimation (under NGERs this is true in all cases except for electricity generation or underground coal mines). Consequently, it is possible that reporters have self selected an emission factor that minimises their emissions i.e. where a higher order method results in an emission factor that is higher than the default a reporter has no incentive to use the higher order method. Due to this possible 'choice bias' the sample will not necessarily be representative of the overall population in these cases and needs to be assessed in every case. This 'choice bias' is removed where higher order methods are mandated.

If a non-representative sample is detected, then the new information is not considered sufficient to justify a re-estimation of the national implied emission factor. While the reported EFs may be incorporated for facilities for which they are known, the emission factor applied to those facilities without EF information is amended to compensate. In this case, the tier 2 /3 method produces a national inventory estimate that is equivalent to the tier 2 method.

What if condition (3) is not maintained? – ie what if the population is determined to be not homogenous?

In some cases, it is possible that sub-populations may exist for which representative samples may be obtained. Within the NGER data obtained for the combustion of black coal, for example, two sub-populations were able to be distinguished. In this case, the general approach identified above would be able to be applied to the sub-population – ie if the sample was sufficiently large, representative and homogenous within the sub-population then the reported EF data may be utilised for that segment of the inventory.





Implications for use of guidelines

The flexibility provided by the Guidelines in the determination of the use of plant specific data leads to a range of possible emission estimates for national inventories that appear to be potentially consistent with the proper application of the Guidelines. To the extent that the Guidelines are designed to assist inventory compilers that do not have perfect information then, as long as compilers provide transparent documentation, this should generally not be an issue. The Guidelines cannot be expected to provide a specific solution for every situation confronting an inventory compiler and reliance on expert judgement provisions is inevitable.

Nonetheless, where there are areas of inventory development where the Guidelines provide for the use of (and reliance on) expert judgement, the development of international understanding of the actual implementation of the Guidelines by inventory practitioners becomes of interest.

IPCC workshops and conferences may have a useful role to perform in assisting inventory compilers and other experts in developing understanding of how to improve national inventories where expert judgements are provided for in the Guidelines.

APPENDIX

The National Greenhouse and Energy Reporting Act 2007 ('the Act') established the legislative framework for a national greenhouse and energy reporting system. The Act provides for an integrated reporting system that will provide the basis for:

- informing government policy formulation and the Australian public;
- meeting Australia's international reporting obligations;
- assisting Commonwealth, State and Territory government programs and activities;
- underpinning the introduction of an emissions trading scheme in the future; and
- avoiding duplication of similar reporting requirements in the States and Territories..

The Act makes reporting mandatory for corporations whose energy production, energy use, or greenhouse gas emissions meet certain specified thresholds.

This Determination is made under subsection 10 (3) of the Act and provides methods, and criteria for methods, for the estimation and measurement of the following items arising from the operation of facilities:

1) greenhouse gas emissions;
2) the production of energy; and
3) the consumption of energy.

The methods governing the estimation of emissions are set out in the *National Greenhouse and Energy Reporting (Measurement) Determination 2008*.

The structure of the Determination is designed to facilitate the integration of corporate and facility level data provided under the Act with international data standards on greenhouse emissions.

The scope of the Determination is given by the following categories of emission sources:

The emission sources are:

- Fuel combustion: emissions from the combustion of fuel for energy (see chapter 2);
- Fugitive emissions from the extraction, production, flaring, processing and distribution of fossil fuels (see chapter 3);
- Industrial process emissions where a mineral, chemical or metal product is formed using a chemical reaction that generates greenhouse gases as a by-product (see chapter 4); and
- Waste emissions from waste disposal - either in landfill, as management of wastewater or from waste incineration (see chapter 5).

The most important source is fuel combustion, which accounts for over 60 per cent of the emissions reported in the national greenhouse gas inventory.

The scope of the Determination does not include land based emissions covered by the IPCC categories 'Agriculture' and 'Land Use, Land Use Change and Forestry'. Emissions from fuel combustion for land based industries are, nonetheless, covered by this Determination.

Methods of measurement

Emissions are rarely measured through direct observation and are most often estimated by reference to readily observable variables that are closely related to greenhouse gas emissions such as the quantity of fossil fuels consumed.

The Determination provides Methods that allow for both direct emissions monitoring and the estimation of emissions through the tracking of observable, closely-related variables. This framework reflects the approaches of the international guidelines governing the estimation of national greenhouse gas inventories and, similarly, national practice such as for the EU *Guidelines for the Monitoring and Reporting of Greenhouse Gas Emissions* and the US Environment Protection Agency *Mandatory Reporting Rule.*

At its simplest, emissions may be estimated by reference to reportable data such as fossil fuel consumption, evidenced by invoices, and the use of specified emission factors provided in the Determination. For emissions from fuel combustion, for example, data on fuel consumption would be multiplied by a specific emission factor for that fuel to generate an emissions estimate. A similar approach has been used for over a decade in the voluntary reporting program *Greenhouse Challenge Plus* and before that, *Greenhouse Challenge*.

Greater levels of complexity and measurement effort may in some circumstances produce better estimates of emissions at facility level. This may result from, for example, sampling and analysis of a fuel consumed for its carbon content and other qualities that will affect actual emissions generated by its combustion at a facility. In Australia, this kind of approach to emissions estimation is already widely used in the electricity industry - in part for commercial reasons and in part because of the reporting processes under the *Generator Efficiency Standards* program.

Direct monitoring of emissions is also potentially an important approach to emissions estimation. While not common, such direct monitoring already occurs in some form in some instances such as in the coal industry, where state legislation requires the monitoring of methane levels for health and safety reasons.

Each of these broad approaches has been incorporated into the Determination as Methods for the estimation of emissions.

In particular four Methods have been described which provide a framework for emissions estimation for a range of purposes.

By drawing on existing emission estimation practices where possible the Determination aimed to minimise the reporting burden on corporations. As indicated above, there are many instances where higher methods (2, 3 and 4 set out below) already reflect current commercial or regulatory practice.

The provision for Reporters to select Methods for the estimation of emissions also allows Reporters to make their own judgments to balance the costs of using the higher methods with the benefits of potentially improved emission estimates.

A framework for Method selection

The four Methods in the Determination can be broadly described by the following:

Method 1: the National Greenhouse Accounts default method

Method 1 provides a class of estimation procedures derived directly from the methodologies used by the Department of Climate Change and Energy Efficiency for the preparation of the *National Greenhouse Accounts*. The use of methodologies from the *National Accounts* anchors Method 1 within the international guidelines adopted by the UN Framework Convention on Climate Change for the estimation of greenhouse emissions.

Method 1 specifies the use of designated emission factors in the estimation of emissions. These emission factors are national average factors determined by the Department of Climate Change and Energy Efficient using the Australian Greenhouse Emissions Information System (AGEIS).

Although significantly updated, this Method is very similar in approach to that used by many corporations for over a decade to report emission estimates under the *Greenhouse Challenge Plus* program.

Method 1 is likely to be most useful for emission sources where the source is relatively homogenous, such as from the combustion of standard liquid fossil fuels, where the emissions resulting from combustion will be very similar across most facilities.

Method 2: a facility-specific method using industry sampling and Australian or international standards listed in the Determination or equivalent for analysis of fuels and raw materials to provide more accurate estimates of emissions at facility level.

Method 2 enables corporations to undertake additional measurements - for example, the qualities of fuels consumed at a particular facility - in order to gain more accurate estimates for emissions for that particular facility.

Method 2 draws on the large body of Australian and international documentary standards prepared by standards organisations to provide the benchmarks for procedures for the analysis of, typically, the critical chemical properties of the fuels being combusted.

Method 2 is likely to be most useful for fuels which exhibit some variability in key qualities, such as carbon content, from source to source. This is the case for coal in Australia.

Method 2 is based on existing technical guidelines used by reporters under the *Generator Efficiency Standards* program. The possibility to report using this, higher order, approach is extended by the Determination from the electricity industry to all major consumers of fossil fuels.

Method 3: a facility-specific method using Australian or international standards listed in the Determination or equivalent standards for both sampling and analysis of fuels and raw materials

Method 3 is very similar to Method 2, except that it requires, additionally, Reporters to comply with Australian or equivalent documentary standards for sampling (of fuels or raw materials) as well as documentary standards for the analysis of fuels.

Method 4: direct monitoring of emission systems, either on a continuous or periodic basis.

Method 4 provides for a different approach to the estimation of emissions. Rather than analysing the chemical properties of inputs (or in some case, products), Method 4 aims to directly monitor greenhouse emissions arising from an activity. This approach can provide a higher level of accuracy in certain circumstances, depending on the type of emission process, however, it is more likely to be more data intensive than other approaches. Such monitoring already occurs, for example, in underground coal mines reflecting the nature of the emission process and the importance of relatively accurate data to support health and safety objectives.

As for Methods 2 and 3, there is a substantial body of documented procedures on monitoring practices and state and territory government regulatory experience that provide the principal sources of guidance for the establishment of such systems.

Facility and Plant Level Data: Incorporating Facility Reported Data into the U.S. GHG Inventory

Lisa Hanle

Invited Background Paper to the IPCC Experts Meeting,

Sydney, Australia, 9 – 11 August 2010

Abstract

Implementation of the first mandatory greenhouse gas (GHG) reporting program in the United States began in earnest in the end of 2009 with publication of the Mandatory Reporting of Greenhouse Gases Rule. This rule established EPA's Greenhouse Gas Reporting Program (GHGRP), which requires large direct emitters of GHGs, and suppliers of fossil fuels and industrial gases to begin data collection in 2010 and report their GHG emissions and other related data to EPA beginning in 2011. Implementation of the GHGRP is a critical milestone for the United States, with the data gathered through the program serving the foundation for future climate policy. Policymakers and stakeholders at the local, state and national level are only beginning to realize what can be done with the reported data. For the first time, the public will be able to better understand some of the large GHG emissions sources in their communities. State and national leaders will be better informed to analyze the GHG emissions implications of potential climate policy options.

Among the many beneficiaries of the data will be the team compiling the Inventory of U.S. GHG Emissions and Sinks (U.S. GHG Inventory). This paper provides a background on the GHGRP and begins to explore the opportunities, and challenges, associated with incorporating the data gathered through that program into the U.S. GHG Inventory. In particular, the paper reviews how the availability of facility-level data could impact the fundamental quality objectives of the inventory- transparency, completeness, consistency, comparability, and accuracy. There are significant opportunities for the United States and many other nations that have facility-level reporting programs to improve their national inventories, as long as the incorporation of that data is done in a deliberative manner with an eye to these quality objectives.

Background

The United States and other developed countries agreed to submit greenhouse gas (GHG) emission reports annually when they signed the Climate Treaty in June 1992 at the Rio Earth Summit. The United States has submitted the Inventory of U.S. Greenhouse Gas (GHG) Emissions and Sinks (the U.S. GHG Inventory) to the Secretariat of the United Nations Framework Convention on Climate Change (UNFCCC) on an annual basis since 1993. Over the years, methods used by the United States to develop the U.S. GHG Inventory have evolved as the international guidelines have advanced and as new and better data sources become available to support Inventory development. The United States continually strives to improve the national Inventory and present the most accurate GHG emissions estimates for both the entire time series and the most recent year for which data are available. This means, as methods evolve and new data sources become available, we are very mindful of the IPCC quality objectives in developing the Inventory: transparency, accuracy, consistency, comparability, and completeness[14].

Transparency: There is sufficient and clear documentation such that individuals or groups other than inventory compilers can understand how the inventory was compiled and can be assured it meets the *good practice* requirements for national greenhouse gas emissions inventories.

Completeness: Estimates are reported for all relevant categories of sources and sinks, and gases.

Consistency: Estimates for different inventory years, gases and categories are made in such a way that differences in the results between years and categories reflect real differences in emissions. Inventory annual trends, as far as possible, should be calculated using the same method and data sources in all years and should aim to reflect the real annual fluctuations in emissions or removals and not be subject to changes resulting from methodological differences.

Comparability: The national greenhouse gas inventory is reported in a way that allows it to be compared with national greenhouse gas inventories for other countries.

[14] 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Edited by Simon Eggelston, Leandro Buendia, Kyoko Miwa, Todd Ngara, Kiyoto Tanabe. Published by the Institute for Global Environmental Strategies (IGES) for the IPCC ISBN 4-88788-032-4

Accuracy: The national greenhouse gas inventory contains neither over- nor under-estimates so far as can be judged.

The United States has a significant opportunity to improve the U.S. GHG Inventory in the coming years with the establishment of the first nationwide mandatory reporting of GHG emissions program in 2009. Certain large emissions source categories in the United States began collecting GHG emissions information and other related data on January 1, 2010 and will report the information to EPA in March 2011, and every year thereafter. This paper provides a background on the EPA Greenhouse Gas Reporting Program and begins to explore the opportunities, and challenges, associated with incorporating the data gathered through that program into the U.S. GHG Inventory.

EPA Greenhouse Gas Reporting Program (GHGRP)

Overview

In October 2009, EPA issued the Greenhouse Gas Reporting Rule (40 CFR Part 98), which requires reporting of GHG emissions and other related data from certain large downstream sources and suppliers of fossil fuels and industrial gases in the United States. Generally, facilities that emit equal to or greater than 25,000 metric tons of carbon dioxide equivalent ($mtCO_2e$) emissions per year are required to submit annual reports to EPA. For some industries, for example, cement production, aluminum production and ammonia production, all or most facilities were estimated to be over the threshold, and therefore all are required to report under the program, regardless of size.

In addition to capturing reporting from downstream emitters, the GHGRP requires all domestic suppliers of petroleum products; coal-based liquids, natural gas, natural gas liquids, and industrial gases, including CO_2, to report the CO_2 emissions that would be released if all fuels were combusted or industrial gases were released to the atmosphere. Importers and exporters of certain fuels and industrial gases are required to report if their potential emissions are equal to or greater than 25,000 $mtCO_2e$. In some case the upstream supplier of a fuel (for example natural gas) will have to report on the GHG emissions assuming complete combustion of all the natural gas that they deliver, while if that natural gas is consumed at a downstream facility that is subject to the rule (e.g., an ammonia manufacturer) the downstream facility must report on the combustion of that fuel. There is inherent double reporting in such a system requiring reporting from upstream suppliers and downstream sources necessitates caution when aggregating the emissions to estimate national GHG emissions.

Coverage.

Figure 1 illustrates the source categories required to collect data in 2010 and submit their first reports to EPA in March 2011. Source categories required to report as a “downstream emitter” are highlighted in yellow, blue or orange. The yellow bars represent source categories for which all facilities the meet the definition of the source category are required to report. Industries highlighted in blue are only required to report if their facility-level emissions are equal to or greater than 25,000 $mtCO_2e$. Other facilities that do not meet the definition of one of listed source categories must still report if their emissions from stationary combustion are equal to or less than 25,000 $mtCO_2e$ (highlighted in orange). Industries highlighted in gray are “suppliers” and most report the CO_2 emissions that would be released if all of the fossil fuel were combusted or the industrial gases were released. Vehicle and engine manufacturers (except light duty vehicles) must report an emissions rate.

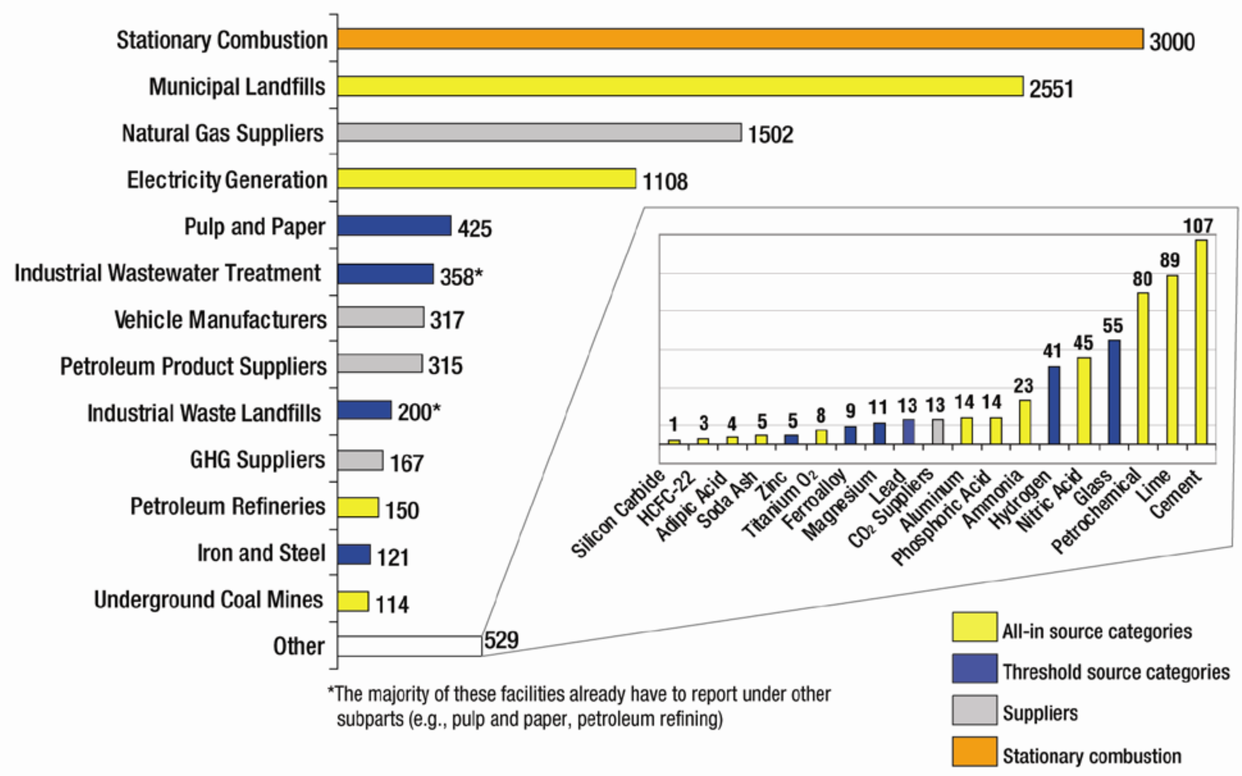


Figure 1. Estimated number of facilities and suppliers that must submit a GHG report

(Manure management, miscellaneous carbonates, and coal to liquid not included)

Table 1 provides additional facilities that must begin data collection on January 1, 2011 and report to EPA in March 2012. A third set of source categories listed in Table 1 have been proposed for inclusion in the Greenhouse Gas Reporting Program, and if finalized as expected, would require facilities to begin data collection January 1, 2011 and submit reports by March 31, 2012.

Table 1. Additional Source Categories under the GHGRP

Will Begin Data Collection January 2011	Will Begin Data Collection January 2011, if Finalized as Proposed
Industrial Landfills	Injection and geologic sequestration of CO_2
Industrial Wastewater	Petroleum and natural gas systems
Magnesium Production	Fluorinated GHG emissions from electronics mfg
Underground Coal Mines	Production of fluorinated gases
	Use of electrical transmission and distribution equipment
	Mfg or refurbishment of electrical equipment
	Import and export of pre-charged equipment and closed cell foams.

Methodological Development

The United States Congress provided the overall framework for what the program should cover (upstream suppliers and downstream sources), but left development and implementation of the program to the U.S. EPA. The GHGRP was designed to support a range of climate change programs, and as such had to be developed in a way that could serve as the foundation for multiple potential future climate policies (e.g., cap and trade, technology specific standards, et cetera). This meant EPA needed to strive to get the most accurate data possible, while still recognizing that the program did not require emissions reductions from reporting facilities. EPA therefore strived to strike an appropriate balance between data accuracy and cost in the calculation methods required.

Identifying the most appropriate methods was perhaps one of the least challenging parts of developing the rule. There was no need to reinvent the wheel. EPA has been developing national estimates for GHG emissions for over 15 years in publishing the *Inventory of U.S. GHG Emissions and Sinks*, using methods published by the Intergovernmental Panel on Climate Change (IPCC) as well as country-specific methods. Different programs at the federal, state, local and corporate level have been incorporating those same or other similar GHG emissions calculations methodologies into their programs. For most source categories, methods for calculating GHG emissions are fairly well established. The key was selecting the appropriate methods for inclusion in the rule.

Bearing in mind the need to balance data accuracy and cost, EPA reviewed the existing methodologies available for the various source categories covered in the rule, modified them as necessary to apply them at the facility-level, and developed a program that relied on use of continuous emissions monitoring systems (CEMS) for facilities where it was a feasible option and the facility already had some of the basic infrastructure in place, and for other source categories required facility-specific calculation methodologies. In limited cases, default emission factors are also allowed. The methodological foundation for the GHGRP is presented in Table 2 below.

Table 2. Methodological Foundation of the GHGRP

Continuous emissions monitoring systems for larger stationary combustion units that meet certain conditions (e.g., burn solid fuel, have concentration monitors or flow meters installed, etc).
Facility-specific calculations for other sources (e.g., stack testing, mass balance, monitoring inputs and site-specific factors).
Methods are prescribed, must follow one of the methods in the rule. In some cases there are choices (e.g., if a facility-specific calculation is prescribed you may still choose to use CEMS).
Simplified methods may be allowed for smaller sources (e.g., fugitive methane emissions at petroleum refineries).
Did not re-invent the wheel- generally used higher-tiered IPCC methods.
Facilities generally required to follow industry consensus standards for monitoring inputs to the equations (e.g., high heating value, carbon content, molecular weight).

Quality Assurance/Quality Control and Verification

Just as it is important to conduct quality assurance and quality control (QA/QC) *throughout* the cycle of GHG Inventory development, it is also critical to ensure that QA/QC and verification are fundamental to a reporting rule's requirements to ensure that the data obtained are of a known and appropriate quality.

To achieve this goal, in many cases the program requires facilities to use standardized calibration, certification, maintenance, and other QA/QC procedures when quantifying GHG emissions. In some instances, the rule allows reporters to use one of several alternative consensus standards or use a method specified by the manufacturer of the device. Where CEMS are used, the facility must comply with either the QA/QC provisions provided in relevant parts of the Clean Air Act, or an applicable State continuous monitoring program. The actual requirements and QA/QC required vary between subparts, and even within a subpart, where options are allowed for reporting. For example, in the final rule, facilities subject only to subpart C (General Stationary Combustion) that use gas chromatography (GC) analysis for high heating value/ carbon content may use GC as long as it is operated, maintained and calibrated according to manufacturer's instructions. However, a hydrogen production facility or a petroleum refinery subject to subpart P or Y must use one of the listed methods in the rule when using a GC. Under Subpart C, a facility may be allowed to use a more simplified method for smaller combustion units, but that same facility could choose to use a more advanced method based on continuous emissions monitors for that same unit. The different approaches to calculating emissions have various levels of stringency in terms of the QA/QC methods and the accompanying data reporting requirements. Once the facility submits the data to EPA, the representative of that facility will attest, under penalty of law, that the emissions estimates are accurate to the best of their knowledge.

The GHG emissions and other related data that were used in the emissions calculations, as well as other data necessary for data verification, are then submitted to EPA electronically. EPA will review the emissions data and supporting data submitted by reporters using electronic checks and auditing tools. The level of verification possible depends on the data reporting requirements for a specific source category. As noted above, this can vary across subparts of the rule, and even within a subpart.

In addition to electronic checks carried out on all data to identify potential calculation and reporting errors, EPA intends to follow-up with facilities should potential errors, discrepancies, or questions arise through the review of reported data. This may be followed up by on-site audits of the data. The goal of these verification steps is to ensure accuracy and completeness, such that EPA and the public are confident in using the data for developing climate policies and potential future regulations.

Use of Facility-Level Data in the U.S. GHG Inventory Now…..

Local, state, national, and perhaps international stakeholders alike eagerly await the GHG emissions data that will be reported to EPA by March 31, 2011. While there are multiple interests and intentions for using the emissions information, the team compiling the U.S. GHG Inventory has started considering how we can use that data to further our national GHG Inventory. Before considering the opportunities, it is good to assess where we are right now in terms of using facility-level data in the GHG Inventory.

In the Inventory, GHG emissions are estimated using methodologies that are consistent with the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC/UNEP/OECD/IEA 1997), the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC 2000), the IPCC Good Practice Guidance for Land Use, Land-Use Change, and Forestry (IPCC 2003), and the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006). The United States continually strives to improve the Inventory and use the best data and highest tiers possible to develop a high-quality inventory. Nevertheless, until now, the United States has not had any legal requirements in place mandating that facilities report GHG emissions, with the exception of the CO_2 emissions reported by utilities under the Acid Rain Program of the Clean Air Act. As such, the Inventory, with limited exceptions, relies predominantly on national-level statistics. Approximately a quarter of the key categories in the most recent inventory are quantified using a Tier 3, or equivalent country-specific method. Table 3 provides a summary of the current methodological approach for some key categories in the Inventory, as well as for some of the sources where Tier 3 or comparable methods are currently followed.

Table 3. Summary of Current Inventory Methods for Selected Source Categories

Source Category	Key Category?	Current Tier	General Approach
General Stationary Combustion (coal, oil and gas)	√	Tier 1/ Tier 2	1. Determine total fuel consumption by fuel type and sector; 2. Subtract consumption of fuel in industrial processes, non energy use of fuels, international bunkers. 3. Apply fuel-specific carbon content
Adipic Acid	√	Tier 2/ Tier 3	For two plants, emission estimates obtained directly from the plant engineer and account for reductions due to control systems in place; for other two facilities emissions calculated by multiplying production by an emission factor and adjusting for the percentage of N_2O released as a result of plant-specific emission controls.
Ammonia Production	√	Tier 1/ Tier 2	Apply CO_2 EF to percent of ammonia produced with natural gas feedstock, separate EF applied to the percentage of ammonia produced from petroleum coke.
Cement Production	√	Tier 2	Apply default clinker EF to the national level production of clinker.
HFC-23 from HCFC-22 Production	√	Tier 3	The five plants measured concentrations of HFC-23 to estimate their emissions of HFC-23. Plants using thermal oxidation to abate their HFC-23 emissions monitor the performance of their oxidizers to verify HFC-23 is almost completely destroyed; plants that release some of their byproduct HFC-23 periodically measure HFC-23 concentrations in the output stream using gas chromatography.
Petroleum and Natural Gas Systems	√	Tier 3	Developed country-specific emission factors for sources in early 1990's, apply emission factors to most recently available activity data.
Underground Coal	√	Tier 3	Ventilation data received from the Mine Safety and Health

Mines	Administration, mine specific approach to estimating degasification and recovery emissions.

Current Inventory Approach and the IPCC Quality Objectives

The U.S. GHG Inventory is annually subject to a peer review, a public review and a review by international experts and continues to be regarded as a high quality Inventory. In general, the inventory has consistently been determined to be transparent, complete, consistent, comparable and accurate.

Transparency

- Inventory is transparently documented. With limited exceptions, all data used to develop the national Inventory are publicly available and can be readily reviewed by external Parties for adherence with international guidelines.
- With the current reliance on national statistics, it can be challenging to ensure that the bodies collecting the underlying statistics adhere to appropriate QA/QC procedures.

Completeness

- Inventory is developed using primarily national-level statistics and default or facility-specific emission factors. Use of national statistics results in a complete inventory that covers the geographic boundaries of the United States.
- For more complex sources, where national statistics are not available and there is no mandatory reporting requirement (e.g., methane capture and destruction at underground coal mines, petroleum and natural gas systems), finding a consistent approach and data sources can be a challenge.

Consistency

- The Inventory generally follows the same methods over the time series. National statistics are typically collected in the same fashion over time, covering the same types of facilities, thereby ensuring time series consistency.

Comparability

- The United States follows the IPCC Guidelines and reporting guidelines established by the UNFCCC ensuring comparability with other reporting parties.

Accuracy

- Current approach provides relatively high certainty of emissions estimates at the national level for most sources; difficult to disaggregate estimates to the facility, state or regional level for policy analysis.

.....and use of Facility-level Data in the Future

The U.S. Inventory is of a very high quality. Nevertheless, there are always opportunities for improvement. Commencement of the first nation-wide reporting obligation is an unprecedented opportunity for the United States to review all aspects of the Inventory development process-- source categories covered, IPCC methods selected, QA/QC procedures, verification and uncertainty analysis, and look for opportunities to further improve the national GHG emissions estimates. The structure of the GHGRP will dictate how useful facility-reported data will be in the national Inventory. Table A-1 in the Appendix provides a crosswalk illustrating the sources covered in the national inventory, whether or not EPA will gather data from the GHGRP, and the accompanying threshold for that source category in the GHGRP.

A couple of points stand out:

- EPA will be collecting at least some data for most source categories in the inventory; categories for which data will not be gathered are primarily in the agriculture and land use, land use change, and forestry sectors. In other words, at the source category level, there is good mapping between the data that will be received from the GHGRP, and the data that will be needed to develop the Inventory. This illustrates a significant opportunity to at least improve most source categories in the inventory, and for some industries to fully replace the current IPCC methods followed and use facility-specific data reported through the GHGRP.

- For source categories with thresholds, a large fraction of the industry may not be subject to reporting. One goal of the GHGRP, after all, was to maximize emissions coverage while minimizing the number of reporters to the program. EPA will need to consider how representative reported data are of national practices? For some industries the fact that only large industries are reporting may not be relevant, as the same practices, fuels, etc., may be used at smaller facilities as well. For other industries, the larger facilities subject to the rule may have vastly different practices and some data obtained from them may not be sufficient for applying to the smaller sources.

The availability of plant-level data could address or partially address many of the current challenges associated with Inventory development. Overall, the GHGRP will help improve the national Inventory by:

- Directly provide the combustion and process-related emissions for some source categories (e.g. ammonia, cement, aluminum) on an annual basis.
- Allowing the United States to better disaggregate national emissions by industry; disaggregate the current stationary combustion estimates by manufacturing sector per reporting guidelines (e.g., iron and steel, non-ferrous metals, chemicals, etc.).
- Ensuring that the underlying data for certain source categories are gathered following very specific methodologies; methodologies that can subsequently be readily reviewed by review teams.
- Enabling the Inventory Agency to develop a relationship with the facilities directly, as opposed to relying on a third party national statistics organization.
- Reducing reliance on default emission factors; develop country-specific (or even more refined) emission factors.
- Providing substantial supporting information in addition to the GHG emissions data that will enable us to verify emissions reported.
- Gather underlying data that can help affirm, or bring into question, previous assumptions used in the Inventory.
- Provide an additional data source to conduct quality assurance/quality control checks.
- Refine the uncertainty analysis by allowing us to rely more on data and less on expert judgment.

Nevertheless, we can already anticipate a number of challenges with incorporating reported GHG emissions information into the national inventory. Some key challenges anticipated include:

- *Time Series Consistency.* Ensuring time series consistency will be a key issue for all source categories, although some will be more difficult than others (e.g., combustion-related emissions information received from facilities using CEMS, petroleum and natural gas systems). Will have to assess source category by source category whether Tier 3 data obtained through the GHGRP is applicable for earlier years. This may be the case where there is minimal penetration of technologies and minimal fuel variability over time.
- *Comparability*. As discussed above, there are only so many ways to quantify emissions from various source categories. Although the uncertainty bands around emissions estimates will narrow as the United States and other countries start implementing higher-tiered and country-specific methods, determining comparability may become more challenging as it may be difficult for inventory reviewers to assess the comparability of methods.
- *Transparency.* There is still uncertainty over how much of the data will be required to be held confidential. EPA is currently undertaking a rulemaking to determine how the data will be handled. Our goal is to make as much available as possible, thereby facilitating transparent review of the data. Nevertheless, some data will inevitably be held as confidential. The extent to which this affects transparency is yet to be determined. In addition, some methods employed by facilities within a given source category may actually result in less verification data reported to EPA, which in turn could introduce challenges with ensuring transparent data presented in the Inventory.

Conclusions

The United States has an unprecedented opportunity to collect more comprehensive GHG emissions information as a result of the first annual GHG reports submitted by facilities in 2011 under the Greenhouse Gas Reporting Program. One can only imagine all of the ultimate uses of the data generated through this program (e.g., project, corporate, national, and even international level). The United States has only just begun to think about the next steps of how to use these data; although it is certain that one important end-user will be the National Inventory system.

It is generally true that Tier 3 data are more accurate and lead to improved emissions estimates. However, incorporation of facility-specific data into national emissions inventories needs to be done in a deliberate manner taking into account the principles of transparency, completeness, consistency, comparability and accuracy, in order to ensure that the national emissions estimates are in fact improved and can be verified as such. As the United States and other countries start incorporating more Tier 3 methods into their national inventories, some key questions for the international community arise, including:

1) What is meant by a Tier 3 method? Are all Tier 3 methods alike?
2) How should Tier 3 methods be presented in the national inventory?
3) Is current IPCC guidance on QA/QC sufficient for Tier 3 methods? How do inventory compilers document facility specific QA/QC activities undertaken?
4) How will the international community assess comparability of Tier 3 methods across Parties?
5) How should uncertainty analyses be conducted where there is variability in methods within a source category? Is the IPCC guidance sufficient to address this?
6) Can Tier 3 methods introduced in 2010 be applied historically? If so, how? Does it depend on the source category?
7) Will confidential business information be more of an issue where inventories are developed using facility-specific data?

One of the great ironies of inventory development is that while higher-tiered methods are desired, it can often be the case that as countries move to higher tiers and develop more country-specific methods more questions arise about the validity of the emissions estimates or the approaches to obtaining the data. These questions about the inventory quality objectives are most certainly valid, but we should not lose site of the fact that collection and use of facility-specific data in the national Inventory presents significant opportunity for countries to improve their national inventory.

Appendix A-1. Crosswalk of U.S. Inventory Source Categories and Data Collected under the GHG Reporting Program beginning in 2011.

Inventory Source Category	Key Category?	Current Inventory Approach	Covered by GHGRP?	Threshold
CO_2				
Stationary Combustion	Y	Tier 2	Y	25,000 mtCO2e
Mobile Combustion	Y	Tier 1, 2	Y (upstream reporters)	All in (domestic) 25,000 mtCO2e (im/exporters)
Non-Energy Use of Fuels	Y	Mass Balance	Y *(Multiple Subparts)*	Varies by subpart
Natural Gas Systems	Y	Tier 3	Proposed (Partial)	25,000 mtCO2e
Cement Production	Y	Tier 2	Y	All in
Lime Production	N	Tier 2	Y	All in
Limestone and Dolomite Use	N	Country-specific	Y *(Multiple Subparts)*	Varies by subpart
Soda Ash Production and Consump	N	Tier 1	Y	All in
Carbon Dioxide Consumption	N	Country-specific	Y *(Production)*	All in (domestic) 25,000 mtCO2e (im/exporters)
Incineration of Waste	N	Tier 2	Partial	25,000 mtCO2e
Titanium Dioxide Production	N	Tier 1	Y	All in
Aluminum Production	N	Tier 2	Y	All in
Iron and Steel Production & Metall	Y	Tier 1, 2	Y	25,000 mtCO2e
Ferroalloy Production	N	Tier 1	Y	25,000 mtCO2e
Ammonia Production and Urea Co	Y	Country-specific	Y	All in
Phosphoric Acid Production	N	Country-specific	Y	All in
Petrochemical Production	N	Country-specific	Y	All in
Silicon Carbide Production and Con	N	Tier 1, Country-specific	Y *(Production)*	All in
Lead Production	N	Tier 1	Y	25,000 mtCO2e
Zinc Production	N	Tier 1	Y	25,000 mtCO2e
Cropland Remaining Cropland	Y	Tier 1, 2, 3	N	N/A
Wetlands Remaining Wetlands	N	Tier 1	N	N/A
Petroleum Systems	N	Tier 3	Proposed (Partial)	25,000 mtCO2e
Land Use, Land-Use Change, and Forestry (Sink)				N/A
International Bunker Fuels	Y	Tier 2	Y (upstream reporters)	All in (domestic) 25,000 mtCO2e (im/exporters)
Wood Biomass and Ethanol Consu	N	Tier 2	Y	25,000 mtCO2e
CH_4				
Stationary Combustion	N	Tier 1	Y	25,000 mtCO2e
Mobile Combustion	N	Model, Tier 1, 2	N	N/A
Coal Mining	Y	Tier 2, 3	Partial	100,000 cubic feet of CH4 per day
Abandoned Underground Coal Min	N	Tier 2, 3	N	N/A
Natural Gas Systems	Y	Tier 3	Proposed (Partial)	25,000 mtCO2e
Petroleum Systems	Y	Tier 3	Proposed (Partial)	25,000 mtCO2e
Petrochemical Production	N	Default	Y	25,000 mtCO2e
Silicon Carbide Production and Con	N	Tier 1	Y *(Production)*	All in
Iron and Steel Production & Metall	N	Tier 1	Y	25,000 mtCO2e
Ferroalloy Production	N	Tier 1	Y	25,000 mtCO2e
Enteric Fermentation	Y	Tier 1, 2	N	N/A
Manure Management	Y	Tier 2	Y	25,000 mtCO2e
Rice Cultivation	N	Tier 2	N	N/A
Field Burning of Agricultural Resid	N	Tier 1, 2	N	N/A
Forest Land Remaining Forest Land				
Forest Fires	Y	Tier 1	N	N/A
Landfills	Y	Tier 2	Y	25,000 mtCO2e generated
Wastewater Treatment	N	Tier 2	Y (Partial)	25,000 mtCO2e
Composting	N	Tier 1	N	N/A
Incineration of Waste	N	Tier 1	Y	25,000 mtCO2e
International Bunker Fuels	Y	Tier 2	N	N/A

Inventory Source Category	Key Category?	Current Inventory Approach	Covered by GHGRP?	Threshold
N_2O				
Stationary Combustion	Y	Tier 1	Y	25,000 mtCO2e
Mobile Combustion	Y	Model, Tier 1, 2	N	N/A
Adipic Acid Production	Y	Tier 2, 3	Y	All in
Nitric Acid Production	N	Tier 2	Y	All in
Manure Management	Y	Tier 2	N	25,000 mtCO2e
Agricultural Soil Management	Y	Tier 1, 3	N	N/A
Field Burning of Agricultural Resid	N	Tier 1, 2	N	N/A
Wastewater Treatment	N	Tier 2	N	N/A
N_2O from Product Uses	N	Country-specific	Y (upstream reporters)	All in (domestic) 25,000 mtCO2e (im/exporters)
Incineration of Waste	N	Tier 1	Y	25,000 mtCO2e
Settlements Remaining Settlements	Y	Tier 2, 3	N	N/A
Forest Land Remaining Forest Land				
Forest Fires	Y	Tier 1	N	N/A
Composting	N	Tier 1	N	N/A
Wetlands Remaining Wetlands	N	Tier 1	N	N/A
International Bunker Fuels	Y	Tier 2	N	N/A
HFCs				
Substitution of Ozone Depleting Sul	Y	Model	Y *(Upstream Reporters)*	All in (domestic) 25,000 mtCO2e (im/exporters)
HCFC-22 Production	Y	Tier 3	Y	All in
Semiconductor Manufacture	N	Tier 1	Proposed	25,000 mtCO2e
PFCs				
Aluminum Production	Y	Tier 2, 3	Y	All in
Semiconductor Manufacture	N	Tier 1	Proposed	25,000 mtCO2e
SF_6				
Electrical Transmission and Distrib	Y	Tier 2, 3	Proposed	25,000 mtCO2e
Semiconductor Manufacture	N	Tier 1	Proposed	25,000 mtCO2e
Magnesium Production and Proces	N	Tier 2	Y	25,000 mtCO2e

Notes: Developed with support from ICF International.

Use of COPERT 4 for the compilation & sub-mission of road transport GHG inventories

L. Ntziachristos

ETC/ACC

Invited Background Paper to the IPCC Experts Meeting,

Sydney, Australia, 9 – 11 August 2010

Background

COPERT 4 is a methodology and software that can be used for the compilation of national emission inventories in the framework of UNFCCC and CLRTAP. For UNFCCC submissions, COPERT may assist national experts in the compilation of their inventories by including the appropriate methodology and emission factors to calculate CO_2, N_2O, and CH_4 emissions from road transport. COPERT (software and/or methodology) is used by 18 out of the 27 EU countries for the preparation and submission of national inventories.

Support for the official use of COPERT 4 in Europe is provided by the European Environmental Agency through the European Topic Centre on Air and Climate Change while its methodology development is coordinated by the ERMES group and is reviewed by TFEIP. The Laboratory of Applied Thermodynamics and their spin-off company EMISIA SA are responsible for the scientific and technical support of the program.

Methodology

The methodology of COPERT 4 is described as the Tier 3 method of the EMEP/EEA emission inventory guidebook, which is directly referenced in the IPCC2006GLs. COPERT 4 has also delivered the aggregated CH_4 and N_2O emission factors for European cars included in the 2006 Guidelines.

Ultimate CO_2 emissions are estimated in COPERT 4 on the basis of fuel consumption only, assuming that the carbon content of the fuel is fully oxidised into CO_2.

In the case of an oxygenated fuel described by the generic chemical formula $C_xH_yO_z$ the ratio of hydrogen to carbon atoms and the ratio of oxygen to carbon atoms are, respectively:

$$r_{H:C} = \frac{y}{x} \qquad r_{O:C} = \frac{z}{x} \tag{1}$$

If the fuel composition is known from ultimate chemical analysis, then the mass fractions of carbon, hydrogen and oxygen atoms in the fuel are *c*, *h*, and *o* correspondingly, where $c + h + o = 1$. In this case, the ratios of hydrogen to carbon and oxygen to carbon in the fuel are respectively calculated as:

$$r_{H:C} = 11.916\frac{h}{c} \qquad r_{O:C} = 0.7507\frac{o}{c} \tag{2}$$

With these ratios, the mass of CO_2 emitted by vehicles in category *j*, combusting fuel *m* can be calculated as:

$$E^{CALC}_{CO_2,j,m} = 44.011 \times \frac{FC^{CALC}_{j,m}}{12.011 + 1.008 r_{H:C,m} + 16.000 r_{O:C,m}} \tag{3}$$

Where FC^{CALC} is the fuel consumption of those vehicles for the time period considered.

Table 1 presents relevant hydrogen to carbon and oxygen to carbon ratios for different fuel types.

Table 1: Ratios of hydrogen to carbon and oxygen to carbon atoms for different fuel types

Fuel (*m*)	Chemical formula	Ratio of hydrogen to carbon	Ratio of oxygen to carbon
Gasoline	$[CH_{1.8}]_x$	$r_{H:C}$=1.80	$r_{O:C}$=0.0
Diesel	$[CH_2]_x$	$r_{H:C}$=2.00	$r_{O:C}$=0.0
Ethanol	C_2H_5OH	$r_{H:C}$=3.00	$r_{O:C}$=0.5
Natural Gas	CH_4 (95%)- C_2H_6 (5%) CH_4 (85%)- C_2H_6 (15%)	$r_{H:C}$=3.90 $r_{H:C}$=3.74	$r_{O:C}$=0.0 $r_{O:C}$=0.0
LPG Fuel A	C_3H_8 (50%)-C_4H_{10} (50%)	$r_{H:C}$=2.57	$r_{O:C}$=0.0
LPG Fuel B	C_3H_8 (85%)-C_4H_{10} (15%)	$r_{H:C}$=2.63	$r_{O:C}$=0.0

The calculation of N_2O, NH_3 and CH_4 emissions is based on cold urban (e_{COLD}), and hot urban, rural and highway emission factors (e_{HOT}), which are provided per vehicle type and technology level. In order to apply the methodology, it is first checked whether the mileage fraction driven at thermally non-stabilised engine conditions (β-parameter) exceeds the mileage share attributed to urban conditions (S_{URBAN}). For each vehicle category j, and pollutant i (i = CH_4, N_2O) the calculation takes the form presented in the following algorithm. In that, N represents the number of vehicles of type j which are driven for M km per year

If $\beta_{i,j} > S_{URBAN;\,j}$

$$E_{COLD\ URBAN;\,i,\,j} = \beta_{i,j} \times N_j \times M_j \times e_{COLD\ URBAN;\,i,\,j}$$

$$E_{COLD\ RURAL;\,i,\,j} = 0$$

$$E_{HOT\ URBAN;\,i,\,j} = 0$$

$$E_{HOT\ RURAL;\,i,\,j} = [S_{RURAL;\,j} - (\beta_{i,j} - S_{URBAN;\,j})] \times N_j \times M_j \times e_{HOT\ RURAL;\,i,\,j}$$

$$E_{HOT\ HIGHWAY;\,i,\,j} = S_{HIGHWAY;\,j} \times N_j \times M_j \times e_{HOT\ HIGHWAY;\,i,\,j}$$

Else if $\beta_{i,j} <= S_{URBAN;\,j}$

$$E_{COLD\ URBAN;\,i,\,j} = \beta_{i,j} \times N_j \times M_j \times e_{COLD\ URBAN;\,i,\,j}$$

$$E_{COLD\ RURAL;\,i,\,j} = 0$$

$$E_{HOT\ URBAN;\,i,\,j} = (S_{URBAN;\,j} - \beta_{i,\,j}) \times N_j \times M_j \times e_{HOT\ URBAN;\,i,\,j}$$

$$E_{HOT\ RURAL;\,i,\,j} = S_{RURAL;\,j} \times N_j \times M_j \times e_{HOT\ RURAL;\,i,\,j}$$

$$E_{HOT\ HIGHWAY;\,i,\,j} = S_{HIGHWAY;\,j} \times N_j \times M_j \times e_{HOT\ HIGHWAY;\,i,\,j}$$

Lube-oil related and SCR oriented CO_2 emissions are not calculated by COPERT. These elements will be introduced in one of the upcoming versions of the software.

Benefits

Use of the COPERT 4 software and methodology can provide a number of benefits to the user, while compiling the submission of an official inventory in the framework of UNFCCC.

In particular, use of the software allows to store and calculate activity data and emissions over a time series within a single file. This means that when input data have been introduced then calculations can take place with the click of a button. This is particularly beneficial in cases where there is a change in the methodology or an emission factor because all years can be automatically updated with the new emission factor. The software also provides a graphical user interface that allows the user to easily manipulate the data and import from/to MS Excel. Finally the software allows to export results directly to CRF (XML) format that can then be directly used for submission.

As regards the benefits offered by the methodology, COPERT includes the methods and the emission factors to calculate emissions practically from all popular vehicle types and technologies, accounting for more than 99.7% of GHG emissions from road transport (urea and lube-oil CO_2 not yet included). It correctly distinguishes between diesel and biodiesel in order to report CO_2 emissions on the basis of fossil fuel only while N_2O and CH_4 emissions take into account the total fuel consumed.

QA/QC

The development and use of COPERT software follow the IPCC recommendations for good practice. *Transparency* is achieved by the methodology which is reviewed by the experts in the Task Force on Emission Inventories and Projections. All methodological items and emission factors are documented in the EMEP/EEA air pollutant emission inventory guidebook. Then, calculations are checked by several users worldwide which use the software for official or private applications. With regard to *completeness*, the software calculates emissions of CO_2, CH_4 and N_2O which correspond to more than 99.7% of total GHG emissions from road transport. For the correct calculation of CO_2 emissions from lube-oil and SCR operation, a Tier 3 methodology would be necessary which is easy to introduce in a next version of the software. *Consistency* is by definition achieved by using a software version for all time-series calculations. The software includes emission factors for practically all vehicle technologies that appeared since 1970 to be introduced until 2020. *Comparability* is also easy to achieve as the inventory is structured in the same way between counties. *Accuracy*, although this is difficult to prove for a complete national inventory, is established by using a widely recognized method. In particular for CO_2, COPERT provides a fuel-balance check where bottom-up calculations (Tier 3) are compared against the statistical one (Tier 1). This can provide a good level of confidence to the calculations.

In addition, a Monte Carlo uncertainty/sensitivity analysis has been conducted on COPERT 4 and has revealed the total uncertainty of the calculations. The report on COPERT uncertainty is available on http://transportpanel.jrc.ec.europa.eu/projects.html.

Outlook

Road transport GHG emissions are projected to decline after 2020 as a result of efficiency improvement measures and the introduction of new, low GHG emission technologies. Still, there is an increasing need for improved calculations as a result of the complex mix of vehicle technologies on the road today and in the future. In this direction, COPERT may assist in compiling an inventory following *good practice* methods. The following updates are expected in the following version of COPERT:

- Inclusion of emission and consumption factors for CNG/LNG cars. CH_4 emission factors are particularly important for NG vehicles.
- Inclusion of Bio-(EtOH, MTBE) to correctly account CO_2 emissions from bio-components in petrol fuel
- Lube-oil consumption estimation which can be introduced as a Tier 3 method, taking into account vehicle type, age and technology.
- Urea-derived CO_2, using a Tier 3 method taking into account vehicle type and technology to estimate emissions
- Other issues of importance in road transport include:
- Development of tiers for urea-derived CO_2
- Improve guidance for CO_2 emission factors (biofuels, oxygen content, etc.)

- Guidance and/or reconciliation AQ needs/ fuel sold requirements. In particular, national experts are some times confused by large deviations when calculating emissions in the framework of UNFCCC and other studies in which air quality is important.
- Guidance on new technologies (hybrids, plug-in hybrids, electric + range extender, …). The distinction between technologies may be necessary. In particular, hybrids are solely based on one fuel (mainly gasoline) while electric vehicles with range extender and plug-in hybrids use two sources (liquid fuel and grid power).
- Impact of model / methodology updates on recalculations (how to predict, account for?) Some guidance may be required to assess the direction that one expects recalculations to take place. I.e. whether more detailed emission factors are expected to increase/decrease emissions.
- PM black carbon effects? This is a more general issue (not specific for road transport). However road transport is a significant source of black carbon from both exhaust and non-exhaust (brake, tires) emissions.

More info and references

COPERT Web-site: http://lat.eng.auth.gr. User's manual, software and methodology are available on the web-site.

EMEP/EEA air pollutant emission inventory guidebook 2009. Technical Report no 9. European Environment Agency. Available online at http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009.

Kouridis, Ch., Gkatzoflias, D., Kioutsioukis, I., Ntziachristos, L., Pastorello, C., Dilara, P. 2010. ***Uncertainty Estimates and Guidance for Road Transport Emission Calculations.*** European Commission, Joint Research Centre, Institute for Environment and Sustainability, Italy. Available online at http://transportpanel.jrc.ec.europa.eu/pdf/projects/TA_uncertainty.pdf.

Ntziachristos, L., Gkatzoflias, D., Kouridis, Ch., Samaras, Z. 2009. ***COPERT: A European Road Transport Emission Inventory Model***. 4th International ICSC Symposium on Information Technologies in Environmental Engineering. May, 28-29, Thessaloniki, Greece.

Annex 3. Co-Chairs Summary

Expert Meeting on Use of Models and Measurements in GHG Inventories

9-11 August 2010, Sydney

Co-Chairs Summary

1. The expert meeting considered the use of models and measurements for all sectors in greenhouse gas emission inventories. In the light of experience to date, the meeting compiled a report on experience and the lessons learnt, particularly related to transparency so that inventory compilers addressing these issues can benefit from this experience.
2. Measured data underlie both models and facility level data. Measurements may be made at individual plant covering all of part of specific sub-sectors, and the meeting noted that there are an increasing number of reporting systems that combine such measured data with other facility level information. In general, models, use measured data for calibration, evaluation and validation to estimate those emissions or removals that cannot be easily otherwise obtained, and so extend limited information to cover national emissions and removals.
3. The use of both models and facility level data in inventories provides significant opportunities to improve the overall quality and, usually, accuracy of the inventory, through, amongst other things, (i) reducing uncertainty and improving uncertainty estimates in the national inventory; (ii) improving spatial and temporal resolution of data and further disaggregating data categories; or (iii) improving potential to correctly estimate impacts of mitigation on national inventories by, for example, reflecting any mitigation effects from measurements or by improving inventory stratification. Therefore their use in the national inventory should be encouraged.
4. The key issue identified in the use of both models and facility level data, is transparency. While approaches to ensuring transparency, documenting and reporting lower Tier approaches are clearly given in the IPCC Guidelines, the use of models and facility level data is only discussed more generally as the specifics depend on national circumstances. The 2006 IPCC Guidelines do provide the overall approach to transparently documenting and reporting these types of data. The meeting noted that clearer descriptions of the approaches used to derive national emissions would help ensure the results understandable and credible and that recent experience provides useful guidance to inventory compilers on how to do this.
5. The meeting compiled lists of typical items that, when reported, may lead to improved transparency. These include:

Models	Facility Level Data
• Basis and type of model • Application and adaptation of the model • Main equations/processes • Key assumptions • Domain of application • How the model parameters were estimated • Description of key inputs and outputs • Details of calibration & model evaluation • Uncertainty and sensitivity analysis • QA/QC procedures adopted • References to peer-reviewed literature	Institutional arrangements • Legal basis • Elements covered • Criteria for data selection • QA/QC • Confidentiality Category-specific • Category emissions • Implied emission factor • Uncertainty • How completeness and time series consistency are ensured

6. The meeting also considered some of the factors inventory compilers need to consider in the use of models and facility level data.
7. For models considerations include: reasons for model selection; interpretation of model results; calibration and parameterisation; evaluation of model methods, processes and results; comparisons with lower tiers and measurements; uncertainty and sensitivity analysis.

8. For facility level data considerations include: do the facility level data definitions match those of the inventory and how has this matching been achieved; does the dataset completely cover a reporting category and if not how this gap has been filled; how has time series consistency between the facility level data and estimates for earlier years has been achieved; and how might these data enhance the quality of inventories.
9. The meeting also considered how the use of these methods can be encouraged. The main barriers to the adoption of complex models are the need for enhanced financial resources and institutional capacity. Access to suitable models, and the ability to modify them, remains a barrier to their use. The participants also noted that the use of models requires a significant, sustained and dedicated effort over the lifetime of the model to collect and update high quality and reliable data at a suitable resolution and to maintain and adapt suitable models.

Thelma Krug
Co-Chair Task Force Bureau

Taka Hiraishi
Co-Chair Task Force Bureau

Annex 4. Meeting Agenda

Monday, 9 August

09:30 –10:00	REGISTRATION	
10:00 –10:30	Welcome	Co-Chairs (TFI) Gary Richards (Australia) Allen Madden (Australia)
10:30 –13:00	Introduction (TSU) 2006 IPCC Guidelines and the use of Tier 3 approaches (TSU) Issues arising from the UNFCCC Inventory review process from the use of plant specific data and complex models, and the reporting of mitigation efforts (UNFCCC) Issues arising from the use of Tier 3 Models in AFOLU and inter-annual variability (Gary Richards, Australia) Discussion	
13:00 –14:00	LUNCH	
14:00 –17:00	Canadian Forest Models (Werner Kurz, Canada) New Zealand's enteric methane/nitrous oxide inventory model and the New Zealand emissions trading scheme (Andrea Pickering, New Zealand) An inventory of CH_4 emissions from rice paddies in China based on Tier 3 approaches (Yao Huang, China) Estimation of national GHG emissions from solid waste disposal site by using field investigation results (Komsilp Wangyao, Thailand) Discussion Comparison of the UK inventory and other EU inventories with the EUETS combustion CO_2 data (John Watterson,UK) Facility data in the Netherlands emission inventory (Rianne Dröge, Netherlands)	

Tuesday, 10 August

10:00 –13:00	The use of facility-specific emission factor data in Australia's national inventory (Rob Sturgiss, Australia) Facility and plant level data: Incorporating facility reported data into the U.S. GHG Inventory (Lisa Hanle, USA) Use of COPERT 4 for the compilation and submission of road transport greenhouse gas inventories (Leonidas Ntziachristos, EEA/ETC) Discussion
13:00 –14:00	LUNCH
14:00 –17:00	Breakout Groups (BOGs) BOG1: Models BOG2: Facility Level Data

Wednesday, 11 August

10:00 –13:00	BOGs continue BOGs agree text for meeting report
13:00 –14:00	LUNCH
14:00 –17:00	Plenary: Agree Draft Meeting Report

Annex 5. Participants

Argentina

Leonidas Osvaldo GIRARDIN
Bariloche Foundation
Piedras 482 2H - Buenos Aires, 1070
Argentina
Tel & Fax: +54 11 4331 2021
logirardin@fundacionbariloche.org.ar
logirardin@gmail.com

Australia

Penny REYENGA
Department of Climate Change and
Energy Efficiency
GPO Box 854, Canberra ACT 2601 Australia
Tel: +61 2 6159 7387
Fax: +61 2 6159 7016
Penny.reyenga@climatechange.gov.au

Gary RICHARDS
Department of Climate Change and
Energy Efficiency
2 Constitution Ave, Canberra ACT, 2601 Australia
Tel: +61 2 6159 7201
Fax: +61 2 6159 7013
Gary.Richards@climatechange.gov.au

Robert STURGISS
Department of Climate Change and
Energy Efficiency
GPO Box 854, Canberra ACT 2601 Australia
Tel: +61 2 6159 7388
Fax: +61 2 6159 7016
rob.sturgiss@climatechange.gov.au

Robert Michael WATERWORTH
Department of Climate Change and
Energy Efficiency
GPO Box 854, Canberra ACT 2601 Australia
Tel: +61 2 6159 7232
Fax: +61 2 6159 7014
robert.waterworth@climatechange.gov.au

Benin

G. H. Sabin GUENDEHOU
Benin Centre for Scientific and
Technical Research
03 P.O. Box 2048 or 1665 Cotonou
Republic of Benin
Tel: +229 95 05 93 91
Fax: +229 21 32 36 71
sguendehou@yahoo.com
guensab@yahoo.fr

Brazil

Thelma KRUG (TFI Co-chair)
INPE - National Institute for Space Research
Av. Dos Astronautas, 1758 - Jardim da Granja,
12227-010 Brazil
Tel: +55 12 3208 6005
Fax: +55 12 3941 2077
thelmakrug@dir.inpe.br
Thelma@dir.iai.int

Canada

Dominique BLAIN
Environment Canada, Science and
Risk Assessment / GHG Division
200 boul Sacré Coeur, 9e étage, Gatineau (Qc)
K1A 0H3 Canada
Tel: +1 819 994 0888
Fax: +1 819 953 3006
dominique.blain@ec.gc.ca

Werner KURZ
Natural Resources Canada,
Canadian Forest Service
506 West Burnside Road, Victoria BC,
V8Z 1M5 Canada
Tel: +1 250 363 6031
Fax: +1 250 363 6004
werner.kurz@nrcan.gc.ca

Chile

Sergio GONZÁLEZ
Instituto de Investigaciones Agropecuarias (INIA)
La Platina Regional Centre,
N° 11610, Santa Rosa Avenue, (La Pintana),
Metropolitan Region of Santiago, 7083150 Chile
Tel: +56 2 7575115/5105
Fax: +56 2 7575347
sgonzale@inia.cl
spe_gonzal@hotmail.com

China

Yao HUANG
Institute of Atmospheric Physics,
Chinese Academy of Sciences
c/o LAPC, Beijing 100029 China
Tel: +86 10 82074294
Fax: +86 10 62041393
huangy@mail.iap.ac.cn

Lingxi ZHOU
Chinese Academy of Meteorological Sciences (CAMS),
China Meteorological Administration (CMA)
CAMS, 46 Zhongguancun Nandajie,
Beijing, 100081 China
Tel: +86 10 58995279
Fax: +86 10 62176414
zhoulx@cams.cma.gov.cn
zhoulx2007@gmail.com

Finland

Teemu Santeri OINONEN
Statistics Finland
Työpajankatu 13, Helsinki,
Postal: P.O.Box 6A, FI-00022
Statistics Finland
Finland
Tel: +358 9 1734 2634
Fax: +358 9 1734 3429
teemu.oinonen@stat.fi
tsoinonen@gmail.com

Guatemala

Edwin CASTELLANOS
Universidad del Valle de Guatemala
18 Ave. 11-95 zona 15, Vista Hermosa III,
Guatemala City, 01015 Guatemala
Tel: +502 2368 8353
Fax: +502 2369 7358
ecastell@uvg.edu.gt

Hungary

Zoltán SOMOGYI
Hungarian Forest Research Institute
Stefánia út 14. Budapest, H-1142
Hungary
Tel: +36 30 465 2684
som9013@helka.iif.hu

India

Nijavalli H. RAVINDRANATH
Centre for Substantial Technologies,
Indian Institute of Science
Bangalore - 560012
India
Tel: +91 80 23341838
Fax: +91 80 2360 1428
ravi@ces.iisc.ernet.in

Indonesia

Rizaldi BOER
Bogor Agriculture University
Centre for Climate Risk and Opportunity Management in Southeast Asia & Pacific Kampus IPB
Baranangszaing, Jalan Raya Pajajaran, Bogor 16134
Tel: +62 811 117660
Fax: +62 251 8313709
rizaldiboer@gmail.com

Japan

Tatsuya HANAOKA
National Institute for Environmental Studies (NIES)
16-2 Onogawa, Tsukuba, Ibaraki, 305-8506
Japan
Tel & Fax: +81 29 850 2710
hanaoka@nies.go.jp

Taka HIRAISHI (TFI Co-chair)
C/o Institute for Global Environmental Strategies (IGES)
2108-11 Kamiyamaguchi Hayama, Kanagawa,
240-0115 Japan
Tel: +81 46 855 3758
Fax: +81 46 855 3808
hiraishi@iges.or.jp

Shigehiro ISHIZUKA
Forestry and Forest Products Research Institute
4-11-16 Kurokami, Kumamoto, Kumamoto
860-0862 Japan
Tel: +81 96 343 3739
Fax: +81 96 344 5054
ishiz03@ffpri.affrc.go.jp

Akihiko ITO
National Institute for Environmental Studies (NIES)
16-2 Onogawa, Tsukuba, Ibaraki, 305-8506
Japan
Tel: +81 29 850 2981
Fax: +81 29 850 2960
itoh@nies.go.jp

Yasuhito SHIRATO
National Institute for Agro-Environmental Sciences
Kan-non-dai 3-1-3, Tsukuba, Ibaraki, 305-8604
Japan
Tel: +81 29 838 8235
Fax: +81 29 838 8199
yshirato@affrc.go.jp

Malawi

Samuel KAINJA
Malawi Water Partnership
P/B 303, Chichiri, Blantyre 3
Malawi
Tel: +265 1 927507
skainja@yahoo.com

Fredrick KOSSAM
Department of Climate Change and Meteorological Services
P.O. BOX 1808, Blantyre
Malawi
Tel: +265 99 5319352 (Mobile)
+265 1 822014 (Office)
Fax: +265 1 822215
fredkossam@yahoo.com

Netherlands

Rianne DROGE
TNO Built Environment and Geosciences
Princetonlaan 6, 3584 CB Utrecht,
The Netherlands
Tel: +31 88 866 20 26
Fax: +31 88 866 20 44
Rianne.droge@tno.nl

New Zealand

Leonard BROWN
Ministry for the Environment
23 Kate Sheppard Place, P.O. Box 10362,
Wellington 6143 New Zealand
Tel: +64 4 439 7504
Fax: +64 4 439 7706
Len.Brown@mfe.govt.nz

Andrea PICKERING
Ministry of Agriculture and Forestry
Pastoral House, 25 The Terrace,
P.O. Box 2526, Wellington 6011
New Zealand
Tel: +64 4 894 0624
Fax: +64 4 894 0741
Andrea.Pickering@maf.govt.nz

Papua New Guinea

Sandro FEDERICI
Coalition for Rainforest Nations
370 Lexington Avenue, 26th Floor,
New York, 10017 USA
Tel: +1 646 448 6870
Fax: +1 646 448 6889
sandro.federici@gmail.com

Republic of Korea

Seungdo KIM
Hallym University
1 Okchon-dong, Dept. of Environmental Sciences and Biotechnology
Chuncheon, Gangwon-do, 200-702
Republic of Korea
Tel: +82 33 248 2153
Fax: +82 33 242 1536
sdkim@hallym.ac.kr

Russia

Anna ROMANOVSKAYA
Institute of Global Climate and Ecology
Glebovskaya str., 20 B, Moscow, 107258
Russia
Tel: +7 499 169 2198
Fax: +7 499 160 0831
An_roman@mail.ru

Senegal

Mamadou KHOUMA
International Development Consulting (IDEV)
B.P. 50037 Dakar R.P. Senegal
Tel: +221 77 632 13 88
Fax: +221 33 855 95 92
khoumamamadou@yahoo.fr

Syria

Sadeddin KHERFAN
Arab University of Science & Technology
Hama - Tal Kartel, P.O. Box 74, 033
Syria
Tel: +963 33 584905
Fax: +963 33 584903
skherfan@yahoo.com

Tanzania

Hubert MEENA
CEEST Foundation
17 Kaunda Drive, Oysterbay, P.O. BOX 5511,
Dar es Salaam Tanzania
Tel: +255 222 667569
hemeena@yahoo.com

Emmanuel Jonathan MPETA
Tanzania Meteorological Agency
Ubungo Plaza, Morogoro Road,
P.O. BOX 3056, Dar es Salaam
Tanzania
Tel: +255 22 2460706/8
Fax: +255 22 2460735
empeta@meteo.go.tz
empeta@yahoo.co.uk

Thailand

Sirintornthep TOWPRAYOON
The Joint Graduate School of Energy and Environment,
King Mongkut's University of Technology Thonburi
126 Prachauthit Rd., Bangmod, Tungkru, Bangkok,
10140 Thailand
Tel: +66 8 17514159
Fax: +66 1 8729805
sirin@jgsee.kmutt.ac.th

Komsilp WANGYAO
The Joint Graduate School of Energy and Environment,
King Mongkut's University of Technology Thonburi
126 Prachauthit Rd., Bangmod, Tungkru, Bangkok,
10140 Thailand
Tel: +66 2 4708309 ex:4152
Fax: +66 2 8729805
komsilp@jgsee.kmutt.ac.th
komsilp@gmail.com

United Kingdom

Jim PENMAN
UK Dept of Energy and Climate Change
3 Whitehall Place, London SW1A 2AW
United Kingdom
Tel: +44 300 068 5646
Jim.penman@decc.gsi.gov.uk

John David WATTERSON
AEA Technology
The Gemini Building, Fermi Avenue, Harwell,
Didcot, Oxfordshire OX11 0QR
United Kingdom
Tel: +44 870 190 6594
Fax: +44 870 190 6318
john.d.watterson@aeat.co.uk

USA

Lisa HANLE
U.S. Environmental Protection Agency
1200 Pennsylvania Ave, NW,
Washington, DC 20460 USA
Tel: +1 202 343 9434
Fax: +1 202 343 2359
Hanle.Lisa@epa.gov

William N. IRVING
Climate Change Division, OAR, USEPA
1200 Pennsylvania Avenue NW,
Washington, DC 20460 (6207J) USA
Tel: +1 202 343 9065
Fax: +1 202 343 2359
Irving.bill@epa.gov

Stephen Michael OGLE
Colorado State University
Natural Resource Ecology Laboratory
Department 1499
Fort Collins, Colorado 80523 USA
Tel: +1 970 491 7662
Fax: +1 970 491 1965
ogle@nrel.colostate.edu

European Topic Centre on Air and Climate Change of the European Environment Agency (EEA/ETC)

Leonidas NTZIACHRISTOS
Aristotle University Thessaloniki
Lab of Applied Thermodynamics,
P.O. Box 458, Thessaloniki,
GR-54124 Greece
Tel: +30 23 10 99 60 03
Fax: +30 23 10 99 60 19
leon@auth.gr
leon.n@emisia.com

UNFCCC

Astrid OLSSON
UNFCCC secretariat
P.O. Box 260 124, D-53153 Bonn
Germany
Tel: +49 228 815 14 50
Fax: +49 228 815 19 99
aolsson@unfccc.int

IPCC TSU

C/o Institute for Global Environmental
Strategies (IGES)
2108-11 Kamiyamaguchi Hayama, Kanagawa,
240-0115 Japan

Simon EGGLESTON
Tel: +81 46 855 3751
Fax: +81 46 855 3808
eggleston@iges.or.jp

Kiyoto TANABE
Tel: +81 46 855 3752
Fax: +81 46 855 3808
tanabe@iges.or.jp

Nalin SRIVASTAVA
Tel: +81 46 855 3754
Fax: +81 46 855 3808
srivastava@iges.or.jp

Jamsranjav BAASANSUREN
Tel: +81 46 855 3757
Fax: +81 46 855 3808
baasansuren@iges.or.jp

Maya FUKUDA
Tel: +81 46 855 3753
Fax: +81 46 855 3808
m-fukuda@iges.or.jp

Eriko NAKAMURA
Tel: +81 46 855 3750
Fax: +81 46 855 3808
nakamura@iges.or.jp

Annex 6. References

Falloon, P. and Smith, P. (2003). Accounting for changes in soil carbon under the Kyoto Protocol: need for improved long-term data sets to reduce uncertainty in model projections. *Soil Use and Management* 19:265-269.

IPCC (1997). Houghton J.T., Meira Filho L.G., Lim B., Treanton K., Mamaty I., Bonduki Y., Griggs D.J., and Callander B.A.(Eds). ***Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories***. IPCC/OECD/IEA, Paris, France.

IPCC (2000). Penman J., Kruger D., Galbally I., Hiraishi T., Nyenzi B., Emmanuel S., Buendia L., Hoppaus R., Martinsen T., Meijer J., Miwa K., and Tanabe K.(Eds.). ***Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories***. IPCC/OECD/IEA/IGES, Hayama, Japan.

IPCC (2003). Penman J., Gytarsky M., Hiraishi T., Krug T., Kruger D.,Pipatti R., Buendia L., Miwa K., Ngara T., Tanabe K. and Wagner F.(Eds.). ***Good Practice Guidance for Land Use, Land Use Change and Forestry***, IPCC/IGES, Hayama, Japan.

IPCC (2006). Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). ***2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme***, Published: IGES, Japan