Uncertainty Analysis in Emission Inventories


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Introduction

• Most important is producing high quality “Good Practice” emission and removal estimates
  – Accurate in the sense that they are systematically neither over- nor underestimates so far as can be judged, and that uncertainties are reduced so far as possible
• Uncertainty in GHG inventory: a lack of knowledge of the true value of a variable that can be described as a probability density function (PDF) characterising the range and likelihood of possible values
• Quantitative uncertainty analysis is performed by estimating the 95 percent confidence interval of the emissions and removals estimates for individual categories and for the total inventory
Specifying Uncertainty

- Uncertainty is quoted as the 2.5 and 97.5 percentile i.e. bounds around a 95% confidence interval.

- This can be expressed, for example:
  - $234 \pm 23\%$
  - $26400 \, (-50\%, +100\%)$
Benefits of Uncertainty Analysis

- **Credibility**: Inventories are estimates – uncertainty analysis gives a clear statement on what we do and do not know.

- **Utility**: Users of the inventory need to know how reliable the numbers are – especially if they are input into policy or inventory improvement actions.

- **Requirement**: Uncertainty analysis is a requirement of all good practice inventories.

- **Scientific**: All scientific analysis should include an uncertainty assessment.
Uncertainty estimation in 2006 IPCC Guidelines

Gather Information
- Collect uncertainty information on activity data and emission factors

Decide approach to use
- Error Propagation
- Monte Carlo

Perform Inventory Analysis
- Spreadsheet
- Software tool
Sources of Uncertainty

• Assumptions and methods
  – The method may not accurately reflect the emissions. Good Practice requires that biases be reduced as much as possible

• Input Data
  – Measured values have errors and EFs may not be truly representative
  – Lack of data (e.g. use of proxies, extrapolation)

• Calculation errors
  – Good QA/QC to prevent these
Sources of Data and Information for Uncertainty

• There are three broad sources of data and information
  – information contained in models
  – empirical data associated with measurements of emissions, and activity data from surveys and censuses
  – quantified estimates of uncertainties based upon expert judgement

• Models can be as simple as arithmetic multiplication of AD and EF for each category and subsequent summation over all categories, but they may also include complex process models specific to particular categories

• Data collection activities should consider data uncertainties. This will ensure the best data is collected and ensures good practice estimates

• Wherever possible, expert judgement should be elicited using an appropriate protocol (e.g. Stanford/SRI protocol)
Methods to Combine Uncertainties

- **Error Propagation**
  - Simple (standard spreadsheet can be used)
    - Guidelines give explanation and equations
  - Difficult to deal with correlations
  - Standard deviation/mean < 0.3

- **Monte Carlo Simulation**
  - More complex (specialised software is used)
  - Needs shape of pdf
  - Suitable where uncertainties large, non-normal distribution, complex algorithms, correlations exist and uncertainties vary with time
# Approach 1: Error Propagation

## Table 3.2

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
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<th>J</th>
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<th>L</th>
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</thead>
<tbody>
<tr>
<td>IPCC category</td>
<td>Gas Base year emissions or removals</td>
<td>Year t emissions or removals</td>
<td>Activity data uncertainty</td>
<td>Emission factor / estimation parameter uncertainty</td>
<td>Combined uncertainty</td>
<td>Contribution to Variance by Category in Year t</td>
<td>Type A sensitivity</td>
<td>Type B sensitivity</td>
<td>Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty</td>
<td>Uncertainty in trend in national emissions introduced by activity data uncertainty</td>
<td>Uncertainty introduced into the trend in total national emissions</td>
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<td>Input data</td>
<td>Input data</td>
<td>Input data Note A</td>
<td>Input data Note A</td>
<td>$\sqrt{E^2 + F^2}$</td>
<td>$\left( G \cdot D \right)^2 \over \left( \sum D \right)^2$</td>
<td>Note B</td>
<td>$D \over \sum C$</td>
<td>$I \cdot F$ Note C</td>
<td>$J \cdot E \cdot \sqrt{2}$ Note D</td>
<td>$K^2 + L^2$</td>
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<td>Gg CO₂ equivalent</td>
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<td>E.g., 1.A.1. Energy Industries Fuel 1</td>
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<td>$\sum M$</td>
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</tbody>
</table>

Enter Emissions Data

Data Calculated using simple equations

Enter Uncertainties

Percentage uncertainty in total inventory: $\sqrt{\sum H}$

Trend uncertainty: $\sqrt{\sum M}$
Uncertainty introduced into the trend in total national emissions

Uncertainty in trend in national emissions introduced by activity data uncertainty

Uncertainty in sensitivity

Approach 1 uncertainty calculation

<table>
<thead>
<tr>
<th>IPCC category</th>
<th>Gas</th>
<th>Year</th>
<th>emissions or removals</th>
<th>Activity data uncertainty</th>
<th>Emission factor estimation parameter uncertainty</th>
<th>Combined uncertainty</th>
<th>Contribution to Variance by Category in</th>
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<td>Type B sensitivity</td>
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<td>Uncertainty in trend in national</td>
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<td>Uncertainty introduced into the trend in</td>
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<td>national emissions</td>
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</tbody>
</table>

AD uncertainties based on source of data

EF uncertainties based on defaults in guidelines

Note short list of source/sinks

<table>
<thead>
<tr>
<th>IPCC category</th>
<th>Gas</th>
<th>Note B</th>
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<tbody>
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</tbody>
</table>

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Approach 2: Monte Carlo Method

• Key Requirements
  – Not just uncertainties but also probability density function (pdf)
    • Mean
    • Width
    • Shape (e.g. Normal, Log-normal, Weibul, Gamma, Uniform, Triangular, Fractile, …)

• Principle
  – Select random values of input parameters from their pdf and calculate the corresponding emission. Repeat many times and the distribution of the results is the pdf of the result, from which mean and uncertainty can be estimated
Probability Density Function

Example Emission Factor

- 2.5th Percentile
- 97.5th Percentile
- 95% Probability Range
- Mean

-30% to +30%

Probability Density

0 1 2 3

Example Emission Factor

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
Probability Density Function

Example Emission Factor

- 2.5\textsuperscript{th} Percentile
- 97.5\textsuperscript{th} Percentile
- 95% Probability Range
- Mean
- -50%
- +100%
Illustration of Monte-Carlo Method

Value

Probability

Emission Factor

Activity Data

Value

Probability

Emission Factor

Activity Data

Value

Probability

Emission = Emission Factor * Activity Data

Select Random Value from distribution

Select Random Value from distribution

Select Random Value from distribution

Select Random Value from distribution

Mean Constant?

Repeat

Total

Store in database

Calculate Mean and Uncertainty

Finish
Example of Monte Carlo Results

![Monte Carlo Results Diagram](image-url)
Summary Results

Number of Runs

Emission

Mean

2.5 percentile

97.5 percentile
Uncertainty Analysis: IPCC Inventory Software

Click "Uncertainty Analysis" to perform analysis.
Uncertainty Analysis: IPCC Inventory Software (cont.)

Click to enter AD and EF uncertainties.
Summary

• Even simple uncertainty estimates give useful information - If they are performed well
• Assessment of uncertainty in the input parameters **should** be part of the data collection
  – Careful consideration will improve estimates as well as providing input data for uncertainty analysis
• If resources limited: effort spent on uncertainty analysis should be small compared with total effort

• **At its simplest a well planned uncertainty assessment should only take a few extra hours!**
  – Uncertainty in AD assessed as data collected
  – Uncertainty in EFs from guidelines now available
  – Aggregate categories/gases to independent groups of sources/sinks
  – Use Approach 1
Thank you