

# Uncertainty Analysis

## GHG Training Workshop Naivasha, Kenya

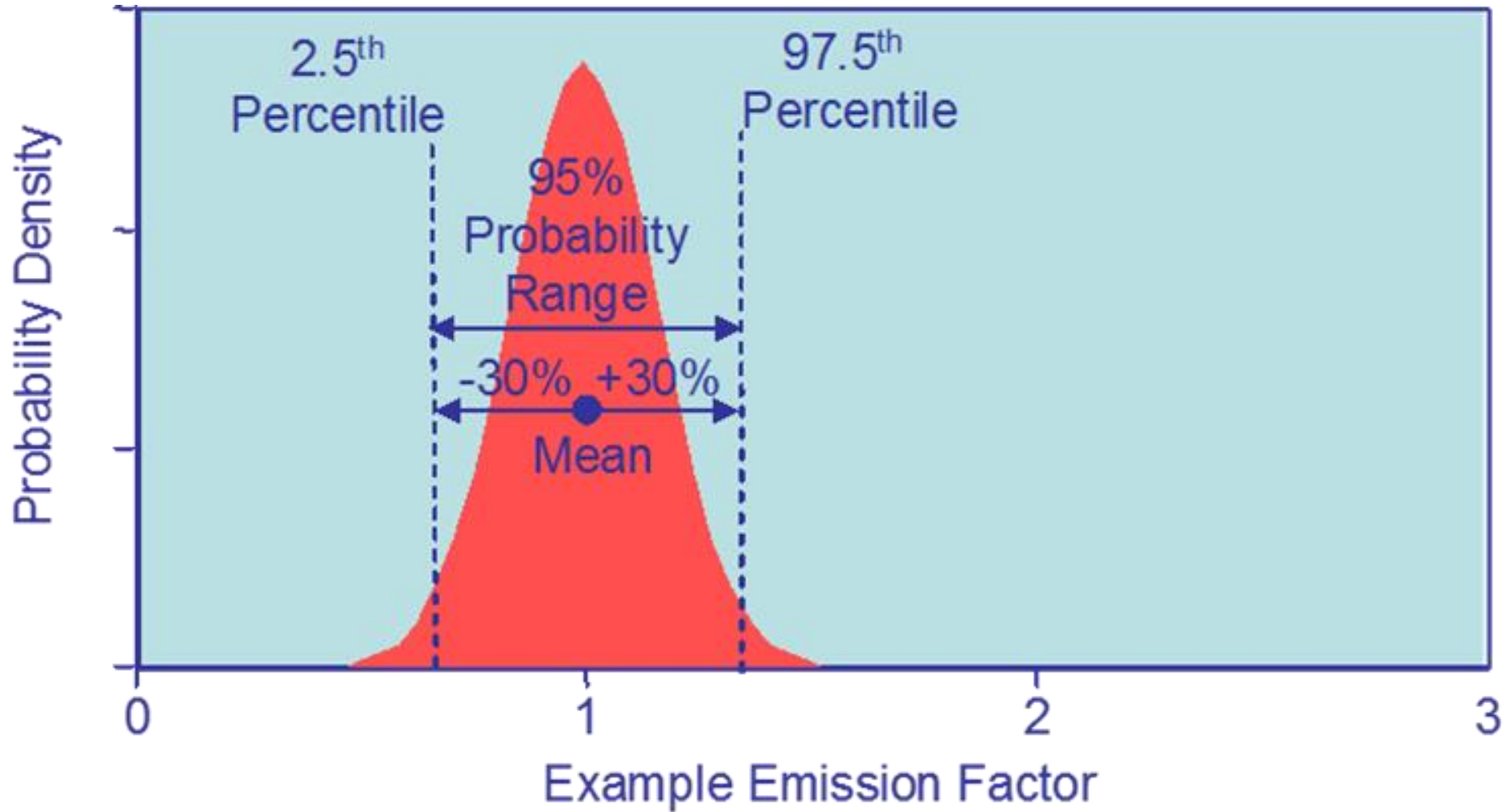
8-12 April , 2024

**Dr Sekai Ngarize**

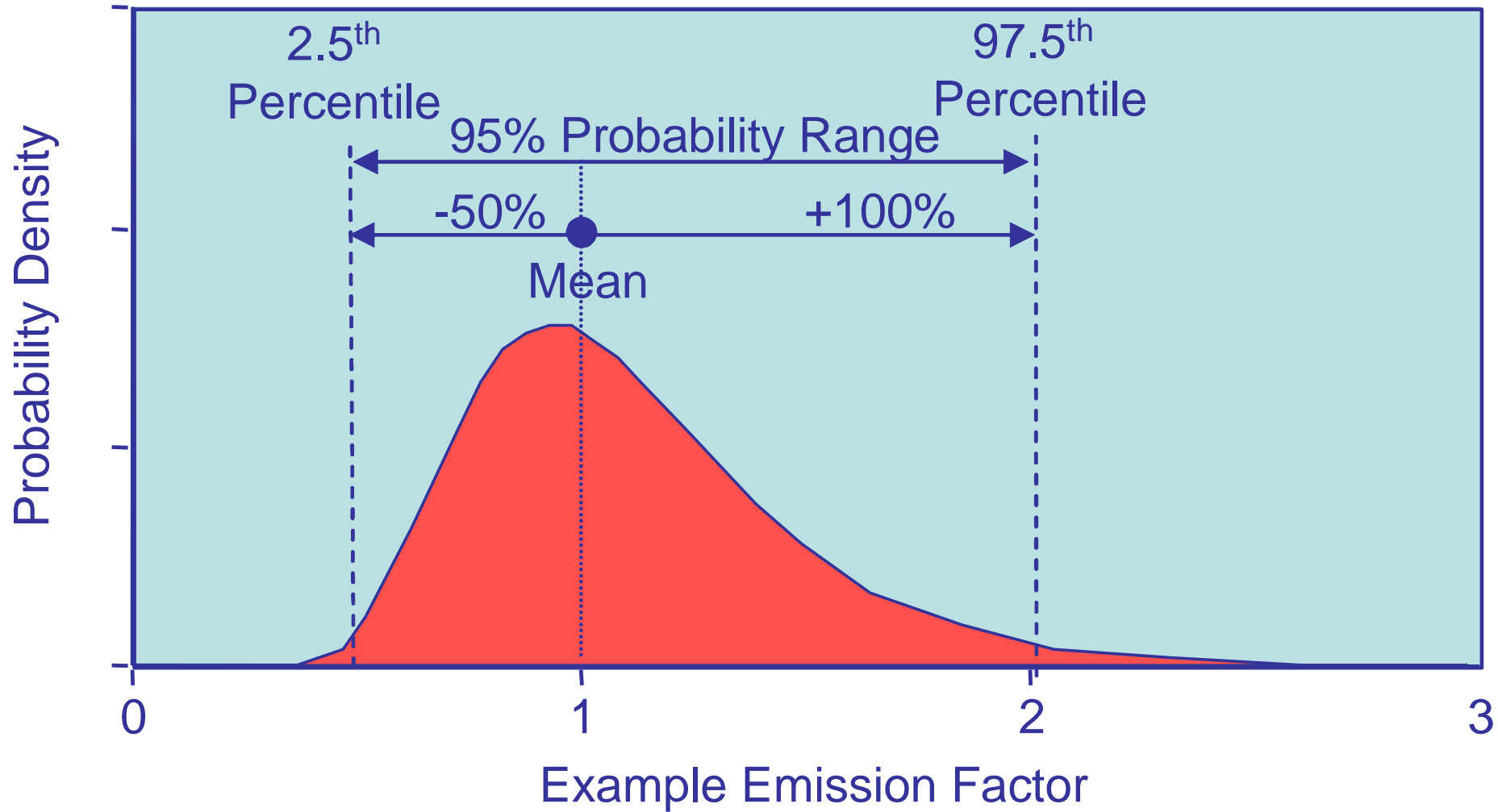
# Introduction

- Uncertainty estimates are an essential element of a complete inventory of GHG emissions/removals
- Uncertainty: a lack of knowledge of the true value of a variable that can be described as a probability density function (PDF) which describes the range and relative likelihood of possible values
- The PDF can be used to describe uncertainty in the estimate of a quantity that is a fixed constant whose value is not exactly known or describe inherent variability.
- 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 (in statistics 95% CI has a 95% probability of enclosing the true value but unknown value of a quantity)
  - 95 percent confidence interval is enclosed by the 2.5<sup>th</sup> and 97.5<sup>th</sup> percentiles of the PDF
  - Familiarise with section 3.2.3.1 in chapter 3, vol. 1 of the 2006 IPCC guidelines. Table 3.2, chapter 3, Vol.1 2006 IPCC

# Probability Density Function

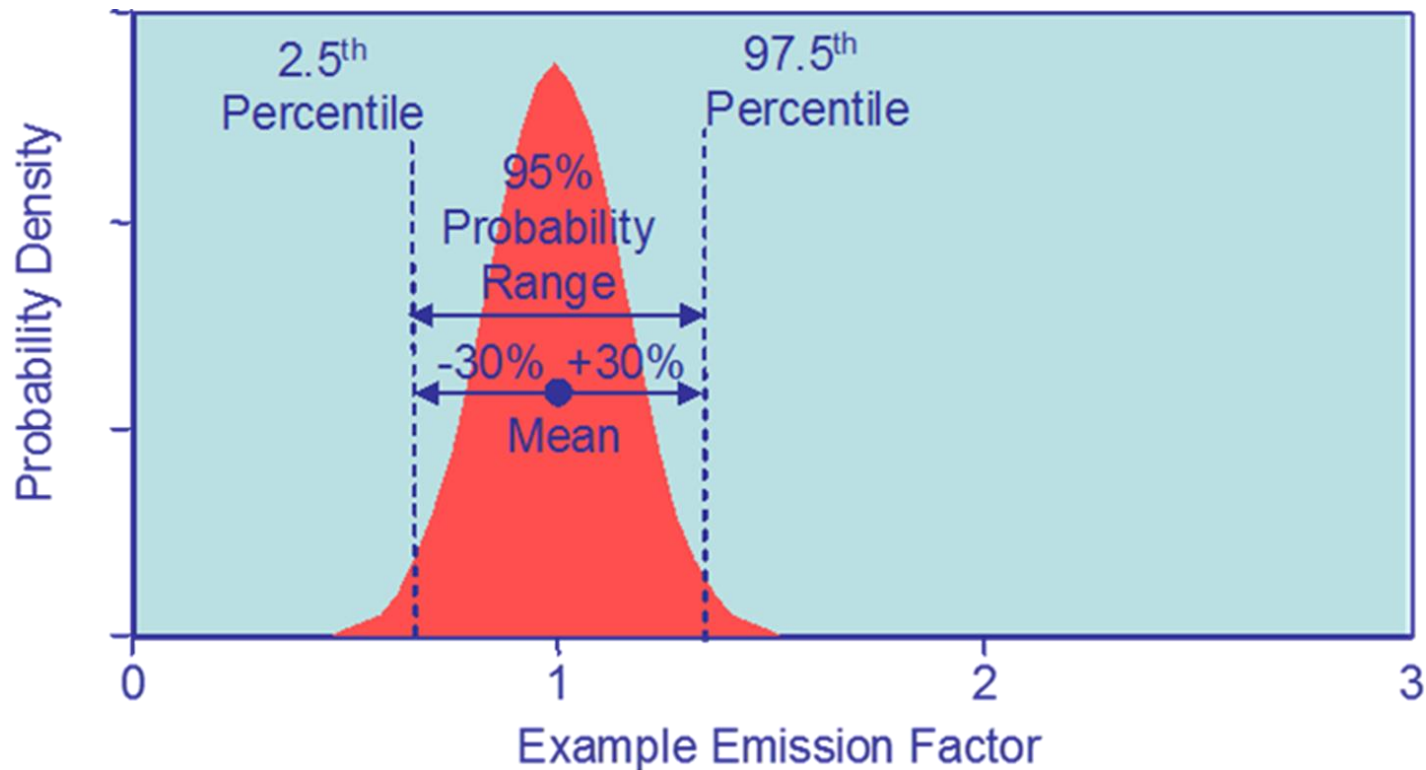


# Probability Density Function



# Specifying Uncertainty

- Uncertainty is quoted as the 2.5<sup>th</sup> and 97.5<sup>th</sup> percentiles i.e. bounds around a 95 percent confidence interval
- This can be expressed, for example:
  - $234 \pm 30\%$
  - 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

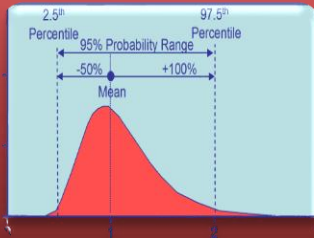
## Requirement

Uncertainty analysis is a requirement of all good practice inventories

## Scientific

All scientific analysis should include an uncertainty assessment

# Uncertainty Estimation



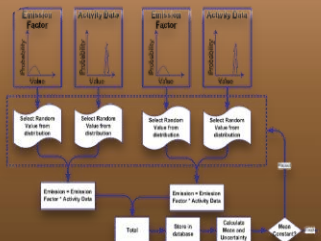
## Gather Information

- Collect uncertainty information on activity data and emission factors

A screenshot of a spreadsheet with multiple columns and rows. The columns are labeled with various parameters and units. The data is organized into several sections, with some cells highlighted in yellow.

## 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
- 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

- There are three broad sources of data and information
  - Information contained in models. 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
  - Empirical data associated with measurements of emissions, and activity data from surveys and censuses
  - Quantified estimates of uncertainties based upon expert judgement
- 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

- Approach 1: Error Propagation
- The IPCC apply propagation method to estimate uncertainty in trend. Generally, the trend is the difference between the emissions in the base year and in the year  $t$ . It is often expressed as % ratio:
  - Simple (standard spreadsheet can be used)
    - Guidelines provide equations and explanations
  - Difficult to deal with correlations
  - Standard deviation/mean  $< 0.3$  ( See practice example)
- Approach 2: Monte Carlo Method
  - More complex (specialised software is used)
    - 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
  - Needs information on PDF (mean, width, shape)
  - Suitable where uncertainties large, non-normal distribution, complex algorithms, correlations exist and uncertainties vary with time

# Error Propagation

Enter Emissions Data

Data Calculated using simple equations

TABLE 3.2  
APPROACH 1 UNCERTAINTY CALCULATION

A	B	C	D	E	F	G	H	I	J	K	L	M
IPCC category	Gas	Base year emissions or removals	Year <i>t</i> emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to Variance by Category in Year <i>t</i>	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
		Input data	Input data	Input data Note A	Input data Note A	$\sqrt{E^2 + F^2}$	$\frac{(G \cdot D)^2}{(\sum D)^2}$	Note B	$\frac{ D }{\sum C}$	$I \cdot F$ Note C	$J \cdot E \cdot \sqrt{2}$ Note D	$K^2 + L^2$
		Gg CO <sub>2</sub> equivalent	Gg CO <sub>2</sub> equivalent	%	%	%		%	%	%	%	%
E.g., 1.A.1. Energy Industries Fuel 1	CO <sub>2</sub>											
E.g., 1.A.1. Energy Industries Fuel 2	CO <sub>2</sub>											
Etc...	...											
Total		$\sum C$	$\sum D$				$\sum H$					$\sum M$
					Percentage uncertainty in total inventory:		$\sqrt{\sum H}$				Trend uncertainty:	$\sqrt{\sum M}$

Enter Uncertainties

Approach 1 uncertainty calculation

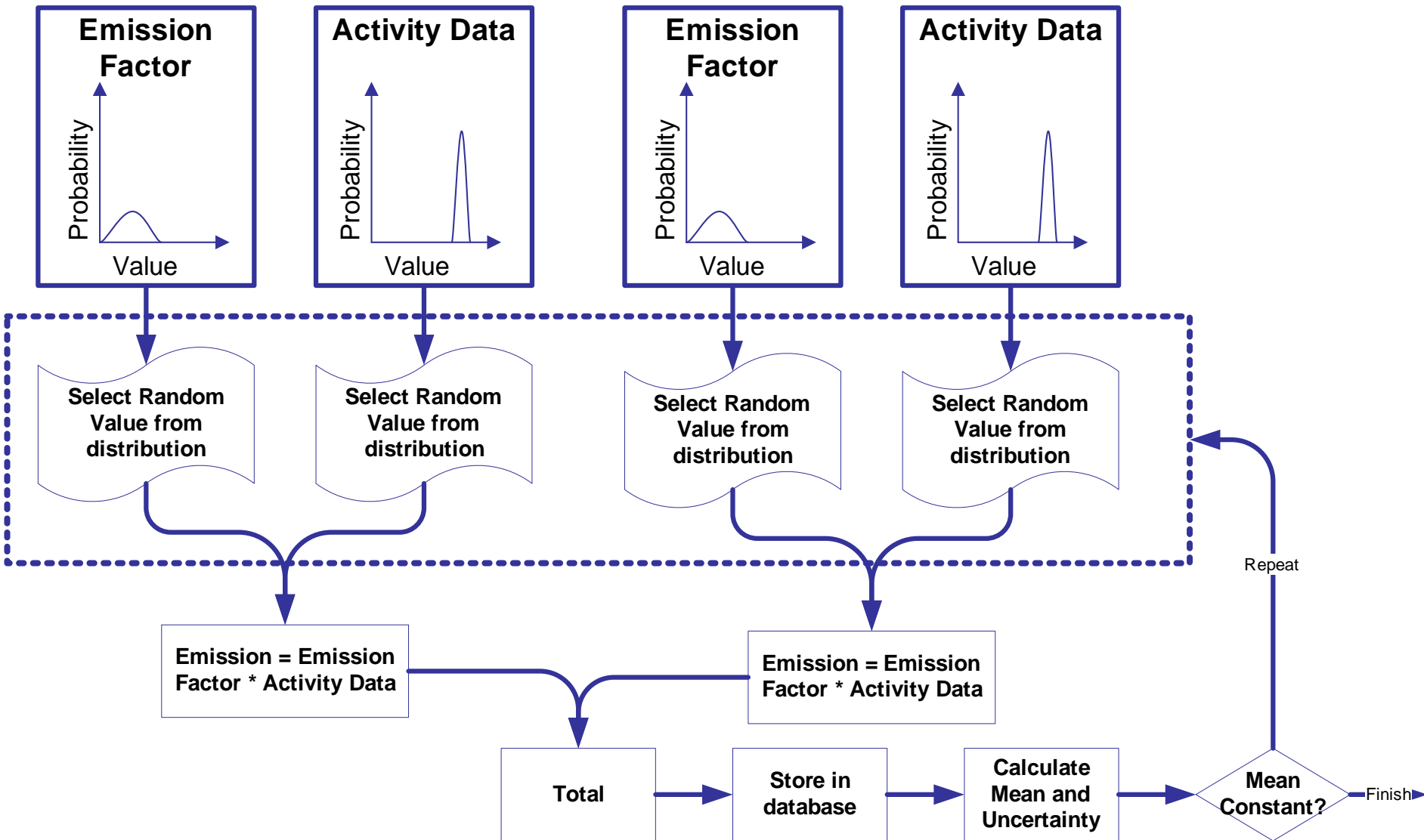
A	B	C	D	E	F	G	H	I	J	K	L	M
IPCC category	Gas	Base year emissions or removals	Year t emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to Variance by Category in	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national	Uncertainty in trend in national	Uncertainty introduced into the trend in total national emissions
			Input data	Input data	Input data	$\sqrt{E^2 + F^2}$	$\frac{(G \cdot D)^2}{(\sum D)^2}$	Note B	$\frac{D}{\sum C}$	I • F	J • E • $\sqrt{2}$	$K^2 + L^2$
		Gg CO <sub>2</sub> equivalent	Gg CO <sub>2</sub> equivalent	%	%	%	%	%	%	%	%	%
1.A.1. Energy Industries	CH4	35.5346662	32.9951217	5	25	25.50	0.0	3.20506E-05	0.00010495	0.000801264	0.000724109	1.19275E-06
1.A.2. Manufacturing Industries and Construction	CH4	57.0302899	51.8776096	5	25	25.50	0.0	4.80131E-05	0.000165011	0.001200328	0.001166804	2.80222E-06
1.A.3. Transport	CH4	81.7067834	37.1466612	5	25	25.50	0.0	-4.94664E-05	0.000118155	-0.00123666	0.000835483	2.22736E-06
1.A.4. Other Sectors	CH4	1041.24025	428.554682	5	25	25.50	0.0	-0.000772946	0.001363136	-0.019323647	0.009638828	0.00046631
1.A.5. Other	CH4	330.338228	97.5658895	5	25	25.50	0.0	-0.000367351	0.000310335	-0.009183772	0.002194401	8.91571E-05
1.B.1. Solid Fuels	CH4	24867.6834	12364.38	10	25	26.93	2.7	-0.011678579	0.039328314	-0.291964463	0.556186352	0.394586505
1.B.2. Oil and Natural Gas	CH4	12570.348	4022.34735	10	25	26.93	0.3	-0.012988732	0.012794183	-0.324718297	0.180937071	0.138180196
2.B. Chemical Industry .	CH4	40.53	37.5018	10	25	26.93	0.0	3.61373E-05	0.000119285	0.000903433	0.001686942	3.66196E-06
4.A. Enteric Fermentation.	CH4	14054.9863	734	4	25	26.93	1.5	-0.005462727	0.023368679	-0.163881819	0.495724537	0.272600067
4.B. Manure Management.	CH4	1903.28061	1199.6	4	25	26.93	0.0	-8.88245E-05	0.003815756	-0.002664735	0.080944413	0.006559099
4.C. Rice Cultivation.	CH4	522.9	30	2	25	26.93	0.0	5.3609E-06	0.001078092	0.000160827	0.015246523	0.000232482
4.F. Field Burning of Agricultural Residues.	CH4	64.3314	3	6	25	26.93	0.0	-1.24107E-05	0.000119565	-0.000372321	0.003381819	1.15753E-05
6.A. Solid Waste Disposal on Land.	CH4	1959.72	37	4	25	26.93	0.4	0.00787088	0.011891742	0.236126385	0.252261939	0.119391756
6.B. Wastewater Handling.	CH4	787.08	747.18	30	25	33.54	0.0	0.000761896	0.002376612	0.022856865	0.050415547	0.003064164
1.A.1. Energy Industries	CO2	102607.31	9596	5	5	7.07	11.2	0.094441853	0.305249301	0.472209267	2.158438506	4.881838378
1.A.2. Manufacturing Industries and Construction	CO2	33991.06	5	5	5	7.07	1.1	0.02618491	0.095945987	0.130924551	0.678440577	0.477422855
1.A.3. Transport	CO2	23987.07	8406.48	5	5	7.07	0.1	-0.022453294	0.026739124	-0.11226647	0.189074157	0.048352797
1.A.4. Other Sectors	CO2	47332.52	11784.04	5	5	7.07	0.2	-0.053800014	0.037482383	-0.269000072	0.265040472	0.14260749
1.A.5. Other	CO2	8370.16	4124.19	5	5	7.07	0.0	-0.004052209	0.013118122	-0.020261045	0.092759127	0.009014766
1.B.2. Oil and Natural Gas	CO2	3408.21	5171.49583	10	15	18.03	0.2	0.009456387	0.016449366	0.141845811	0.232629165	0.074236563
2.A. Mineral Products.	CO2	5744.63	2507.20146	10	15	18.03	0.0	-0.003809586	0.007974844	-0.057143788	0.112781331	0.015985041
2.B. Chemical Industry .	CO2	1355.56	171.93456	10	15	18.03	0.0	-0.002233954	0.000546885	-0.033509311	0.007734125	0.001182691
2.C. Metal Production.	CO2	12932.6799	10507.4715	10	15	18.03	0.9	0.006887639	0.033421905	0.103314586	0.47265712	0.234078657
5.A. Changes in Forest and Other Woody Bioma	CO2	97.19		50	80	94.34	0.0	-0.000199385	0	-0.015950798	0	0.000254428
5.A. Changes in Forest and Other Woody Bioma	CO2	-7810.79	-7721.7341	50	80	94.34	12.9	-0.008539362	0.024561101	-0.683148991	1.736732102	3.482930938
5.B. Forest and Grassland Conversion.	CO2	6.26	280.43888	25	75	79.06	0.0	0.00087917	0.000892013	0.065937785	0.031537424	0.005342401
1.A.1. Energy Industries	N2O	388.516902	328.741673	5	50	50.25	0.0	0.000248607	0.001045653	0.012430334	0.007393886	0.000209183
1.A.2. Manufacturing Industries and Construction	N2O	112.709781	114.844426	5	50	50.25	0.0	0.000134069	0.000365294	0.006703468	0.002583021	5.16085E-05
1.A.3. Transport	N2O	57.3319301	21.6195922	5	50	50.25	0.0	-4.88495E-05	6.87671E-05	-0.002442474	0.000486257	6.20212E-06
1.A.4. Other Sectors	N2O	194.497577	46.1816455	5	50	50.25	0.0	-0.000252117	0.000146893	-0.001260587	0.001038693	0.000159987
1.A.5. Other	N2O	27.4386549	13.5195061	5	50	50.25	0.0	-1.3288E-05	4.30025E-05	-0.000664398	0.000304074	5.33886E-07
4.B. Manure Management.	N2O	375.1	198.4	15	30	33.54	0.0	-0.000138451	0.000631066	-0.004153541	0.013386927	0.000196462
4.D. Agricultural Soils(2).	N2O	25217.694	9798.17	20	30	36.06	3.0	-0.020551916	0.031165777	-0.616557485	0.881501284	1.157187646
4.F. Field Burning of Agricultural Residues.	N2O	24.304	21.297	20	30	36.06	0.0	1.78812E-05	6.7741E-05	0.000536437	0.001916004	3.95884E-06
6.B. Wastewater Handling.	N2O	452.6	384.4	15	30	33.54	0.0	0.000294175	0.00122269	0.008825264	0.025937172	0.000750622
Keep Blank!											0	
Total		314388.7626	202771.1719			$\sum H$	34.6				$\sum M$	11.4670044
					Percentage uncertainty in total inventory:		5.880740472				Trend uncertainty:	3.386296561

AD uncertainties based on source of data

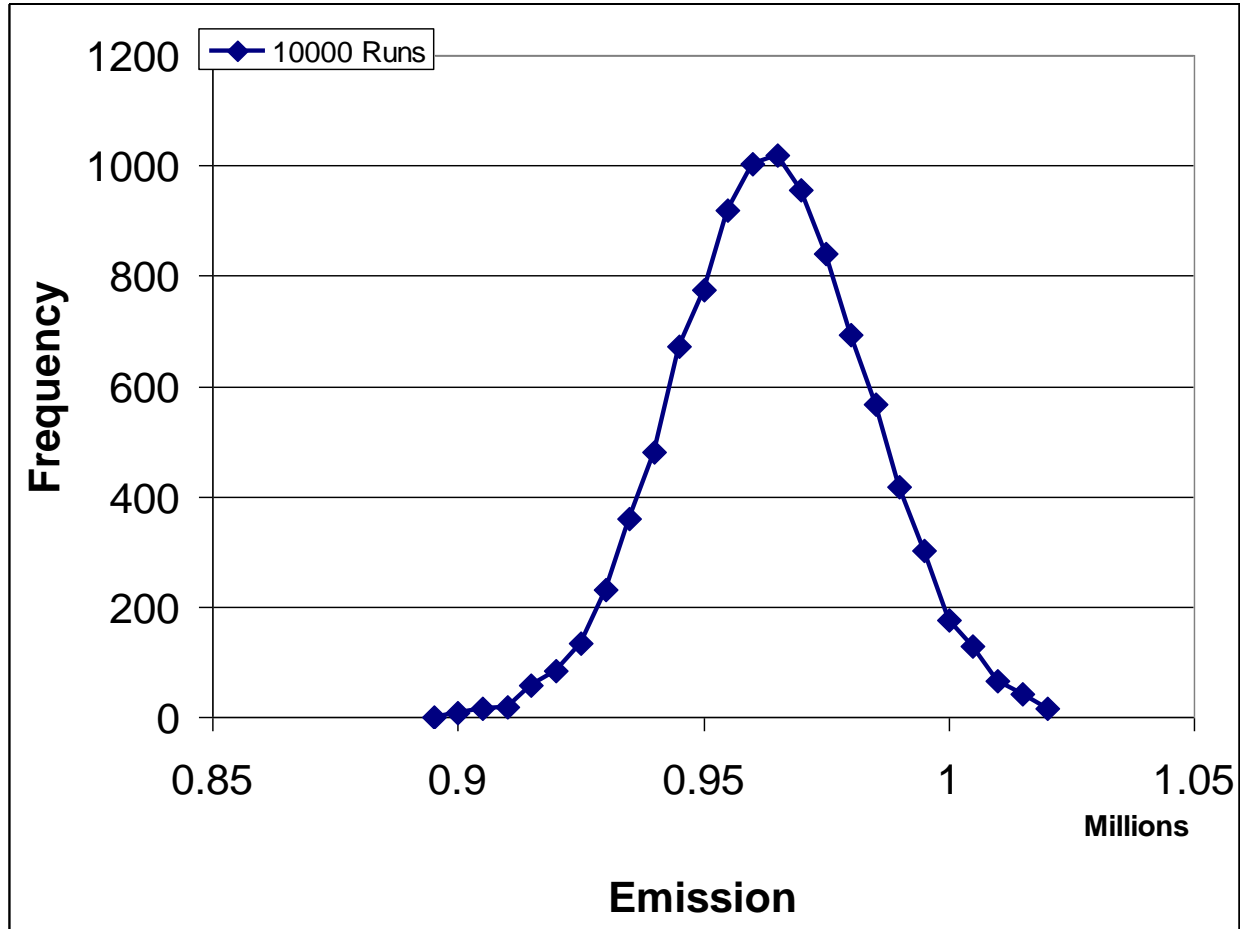
EF uncertainties based on defaults in guidelines

Note short list of source/sinks

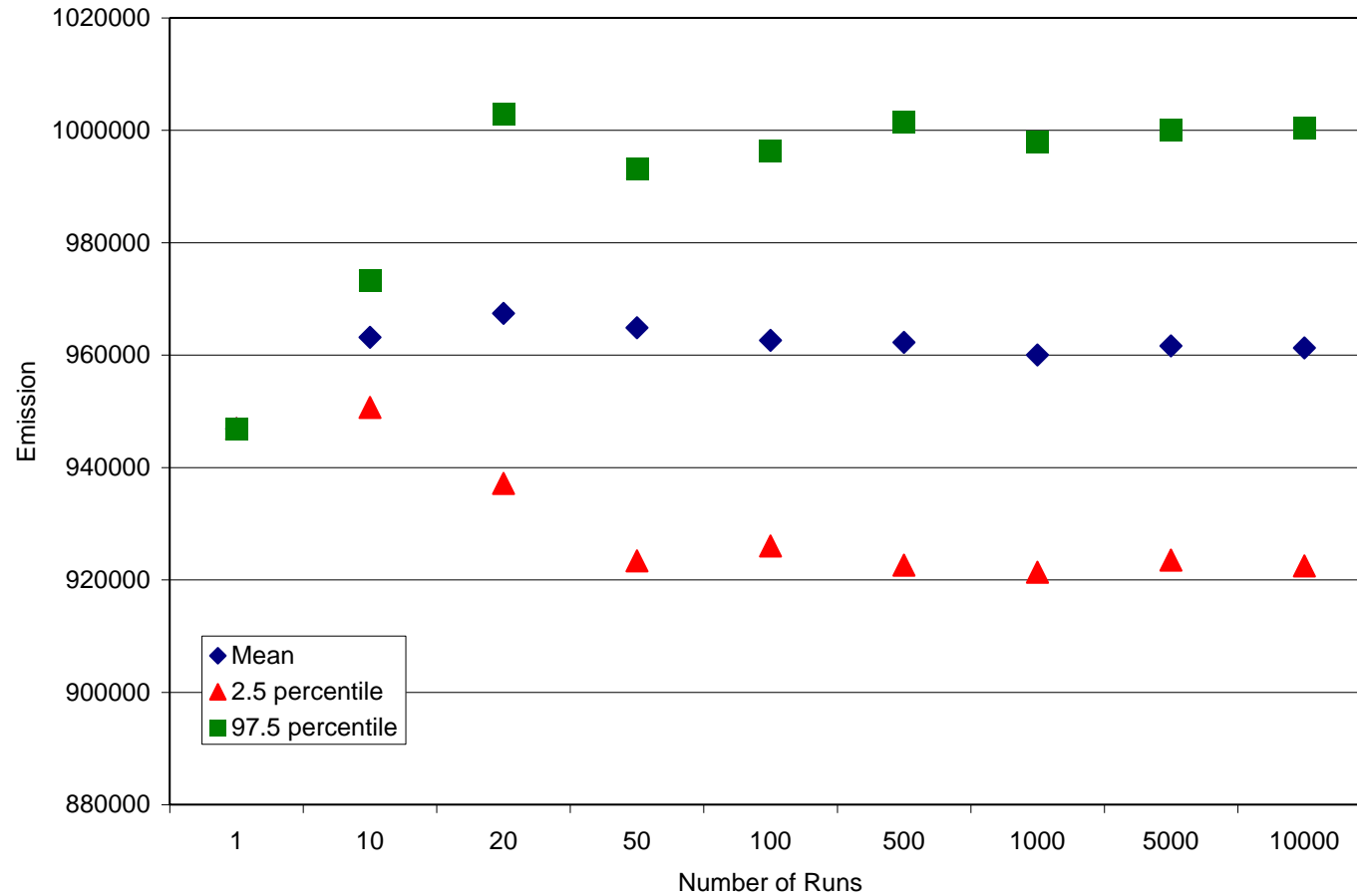
# Illustration of Monte-Carlo Method



# Example of Monte Carlo Results



# Summary Results



# IPCC Inventory Software: Uncertainty Analysis

Application Database Inventory Year Worksheets Reports **Tools** Export/Import Administrate Window Help

2006 IPCC Categories

- 4.A - Solid Waste Disposal
  - 4.A.1 - Managed Waste Disposal Sites
  - 4.A.2 - Unmanaged Waste Disposal Sites
  - 4.A.3 - Uncategorised Waste Disposal Site
- 4.B - Biological Treatment of Solid Waste
- 4.C - Incineration and Open Burning of Waste
  - 4.C.1 - Waste Incineration
  - 4.C.2 - Open Burning of Waste
- 4.D - Wastewater Treatment and Discharge
  - 4.D.1 - Domestic Wastewater Treatment
  - 4.D.2 - Industrial Wastewater Treatment and Discharge
- 4.E - Other (please specify)
- 5 - Other
  - 5.A - Indirect N2O emissions from the atmosphere
  - 5.B - Other (please specify)

Parameters Methane Calculations Methane Recovered Methane Deposited Methane Calculations Methane Recovery Results Long Term s 1994

Worksheet

Sector: Waste  
 Category: Methane  
 Subcategory: 4.A - Solid Waste Disposal  
 Sheet: Results

Data

Year	Methane generated							Methane recovered	Methane deposited	Methane balance
	Food	Garden	Paper	Wood	Textile	Nappies	Other			
	A (Gg)	B (Gg)	C (Gg)	D (Gg)	E (Gg)	F (Gg)	G (Gg)			
1950	0	0	0	0	0	0	0	0	0	0
1951	0.56846	0.02109	0.73922	0.13806	0.09562	0.01265	0.13753	7.81853	9.53118	9.53118
1952	1.10382	0.04115	1.44946	0.27339	0.1875	0.02469	0.26836	15.25575	18.60412	18.60412
1953	1.608	0.06023	2.13185	0.40604	0.27577	0.03614	0.3928	22.33025	27.24109	27.24109

Click "Uncertainty Analysis"

Application Database Inventory Year Worksheets Reports Tools Export/Import Administrate Window Help

Uncertainty Analysis - Approach 1 (Table 3.2)

Base year for assessment of uncertainty in trend 1990 Year T 1994

2006 IPCC Categories	Gas	Base Year emissions or removals (Gg CO2 equivalent)	Year T emissions or removals (Gg CO2 equivalent)	Activity Data Uncertainty (%)
<b>4.A - Solid Waste Disposal</b>				
	CH4	3598.6	3705.4	3.0
<b>4.B - Biological Treatment of Solid Waste</b>				
	CH4	81.8	0.0	0.0
	N2O	39.5	0.0	0.0
<b>4.C - Incineration and Open Burning of Waste</b>				
4.C.1 - Waste Incineration	CO2	1419.2	5501.4	4.0
	CH4	11.7	1.9	4.0
	N2O	0.0	480.1	4.0
4.C.2 - Open Burning of Waste	CO2	69.2	2203.1	4.0
	CH4	0.0	4.2	4.0
	N2O	1.0	34.1	4.0
<b>4.D - Wastewater Treatment and Discharge</b>				
4.D.1 - Domestic Wastewater Treatment and Discharge	CH4	5.0	0.1	5.0
	N2O	0.2	0.1	5.0

Number of decimal places 1  Zero padding

Refresh Data Export to Excel

Click to perform analysis



# IPCC Inventory Software: Uncertainty Analysis (cont.)

The screenshot displays the IPCC Inventory Software interface. The main window shows the 'Parameters' tab for 'Methane Correction Factor' for 'Slovakia' in the 'Europe - Eastern' region, using a 'Waste by composition' approach and 'National data' activity data. The '2006 IPCC Categories' tree on the left highlights '4.A - Solid Waste Disposal'. A 'DOC (Degradable organic carbon)' table is visible, listing categories like Food Waste, Garden, Paper, etc., with their respective weight fractions. An 'Uncertainties' dialog box is open, showing settings for '4.A - Solid Waste Disposal' with activity data uncertainties of -3.00% to +3.00% and emission factor uncertainties of -2.00% to +2.00% for METHANE (CH4). A purple callout box points to the 'Uncertainties' button in the main window, with the text 'Click to enter AD and EF uncertainties'. A 'Time Delay' text box is also visible in the bottom left corner.

**2006 IPCC Guidelines**  
**Time Delay**  
The default assumption is that the first of January in the year is equivalent to an average decay to methane commencing good practice to assume a delay time of six months. If a value greater than six months is supported by evidence to support this model work for delay time number 13 in "exp2" in the sheets is changed to 25. G is readdressed one cell

**Parameters** | Methane Correction Factor | Activity Data | Amount Deposited | Methane Calculations | Methane Recovery | Results

**Country/Territory** Slovakia  
**Region** Europe - Eastern  
**Approach** Waste by composition  
**Activity Data** National data

Starting year: 1950  
DOCf (fraction of DOC dissimilated): 0.500  
Delay Time (months): 6  
Fraction of methane (F) in developed gas: 0.500  
Conversion Factor, C to CH4: 1.333333  
Oxidation Factor (OX): 0.00  
Parameters for carbon storage: % paper in industrial waste: 0.00 %

DOC (Degradable organic carbon) [weight fraction, wet basis]	Methane generation rate con
Food Waste: 0.150	Food Waste
Garden: 0.200	Garden
Paper: 0.400	Paper
Wood and straw: 0.430	Wood and straw
Textiles: 0.240	Textiles
Disposable nappies: 0.240	Disposable nappies
Sewage sludge: 0.050	Sewage sludge
Industrial Waste: 0.150	Industrial Waste

**Uncertainties**  
Category: 4.A - Solid Waste Disposal  
Activity Data Uncertainties: Lower: -3.00 %, Upper: +3.00 %  
Emission Factors Uncertainties: Gas: METHANE (CH4), Lower: -2.00 %, Upper: +2.00 %

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**