Uncertainty Analysis in Emission Inventories

Africa Regional Workshop on the Building of Sustainable National Greenhouse Gas Inventory Management Systems, and the Use of 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Maseru, Lesotho

14–18 March 2016

Kiyoto Tanabe

Technical Support Unit, IPCC TFI

WMO UNEP

ipcc

INTERGOVERNMENTAL PANEL ON climate change

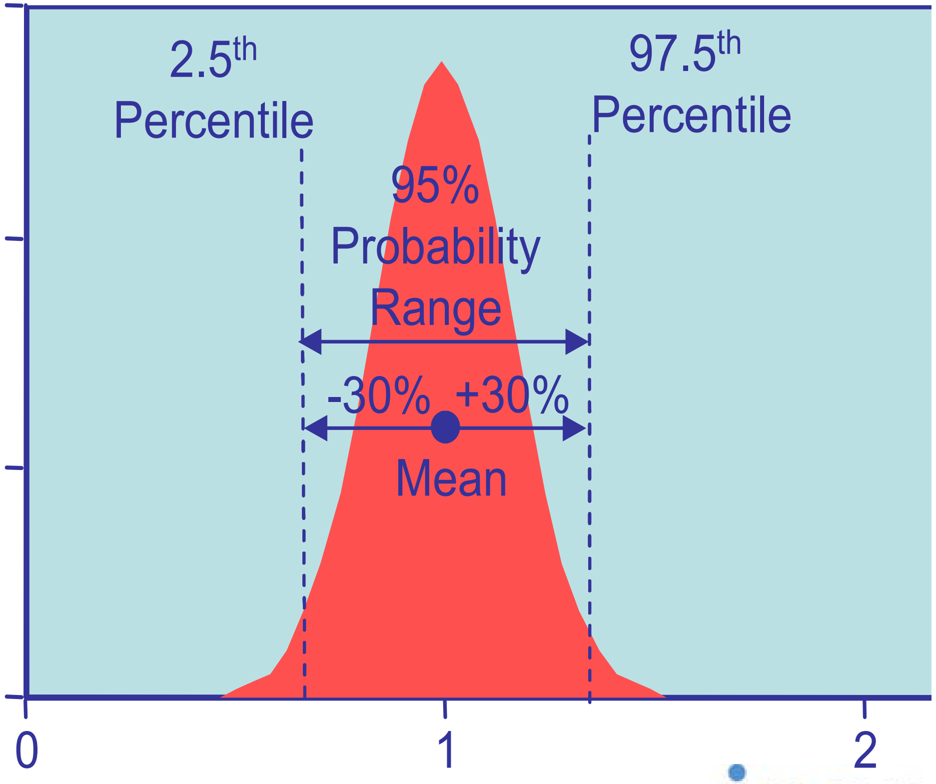
Introduction

- 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 ± 23%
  - 26400 (- 50%, + 100%)



INTERGOVERNMENTAL PANEL ON climate change

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

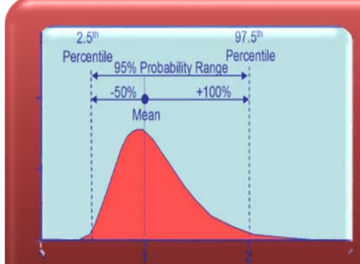
Requirement

Uncertainty analysis is a requirement of all good practice inventories

Scientific

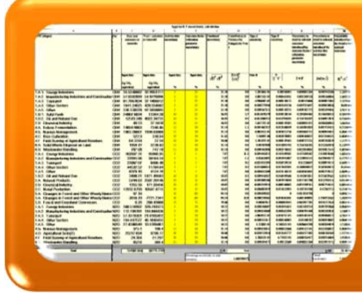
All scientific analysis should include an uncertainty assessment

Uncertainty estimation in 2006 IPCC Guidelines



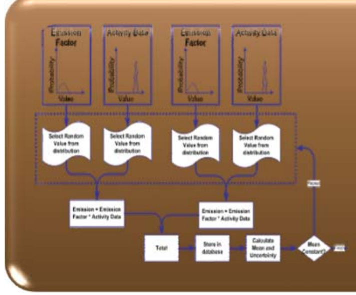
Gather Information

- 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

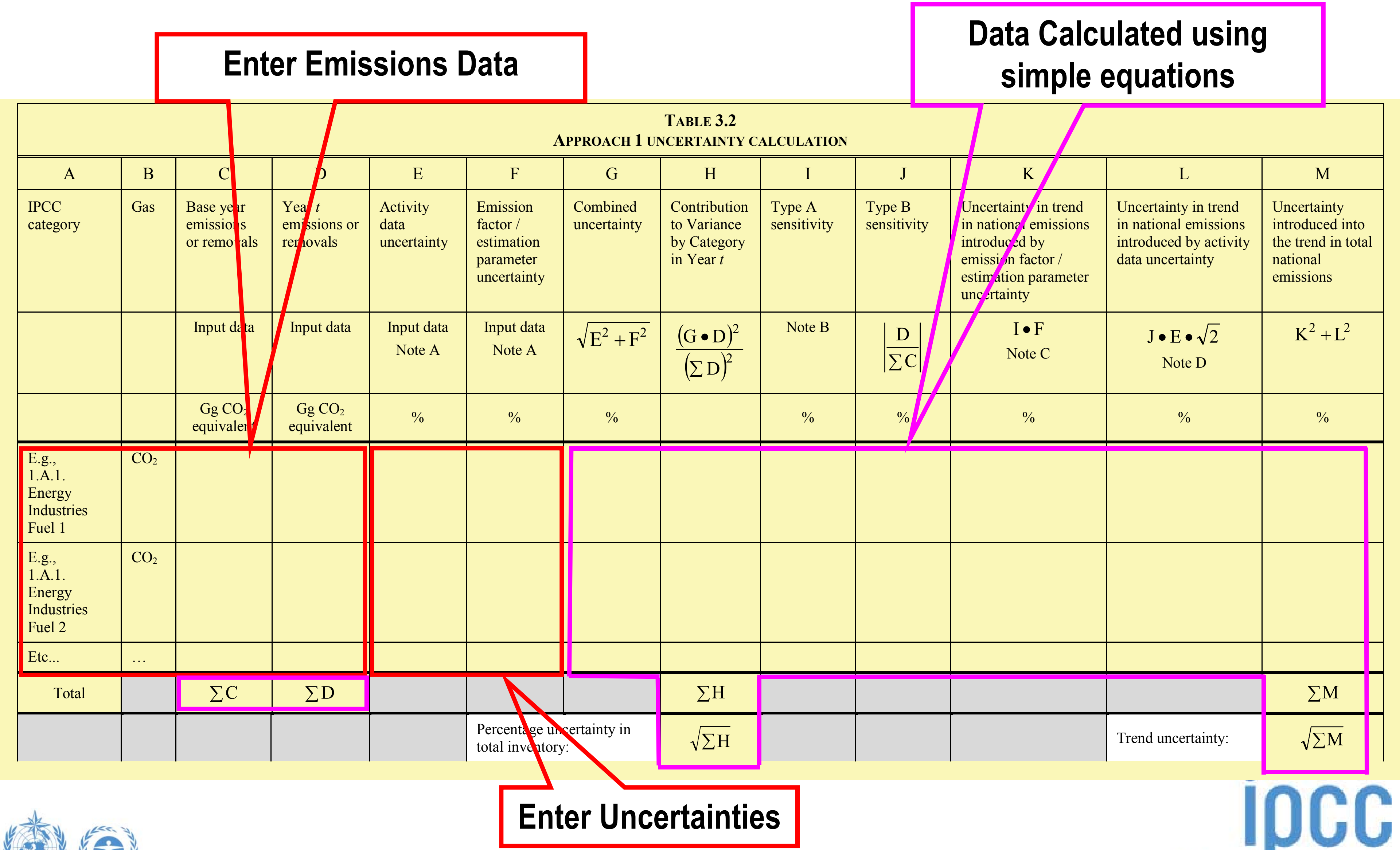
Sources of Data and Information for Uncertainty

- 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



Enter Emissions Data

Data Calculated using simple equations

Enter Uncertainties

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 *t* emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to Variance by Category in Year *t*	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	$\sqrt{E^2+F^2}$	$\frac{(G \bullet D)^2}{(\sum D)^2}$	Note B	$\left\lvert\frac{D}{\sum C}\right\rvert$	$I \bullet F$ Note C	$J \bullet E \bullet \sqrt{2}$ Note D	K^2+L^2
		Gg CO_2 equivalent	Gg CO_2 equivalent	%	%	%		%	%	%	%	%
E.g., 1.A.1. Energy Industries Fuel 1	CO_2											
E.g., 1.A.1. Energy Industries Fuel 2	CO_2											
Etc...	…											
Total		$\sum C$	$\sum D$				$\sum H$					$\sum M$
					Percentage uncertainty in total inventory:		$\sqrt{\sum H}$				Trend uncertainty:	$\sqrt{\sum M}$

AD uncertainties based on source of data

EF uncertainties based on defaults in guidelines

Note short list of source/sinks

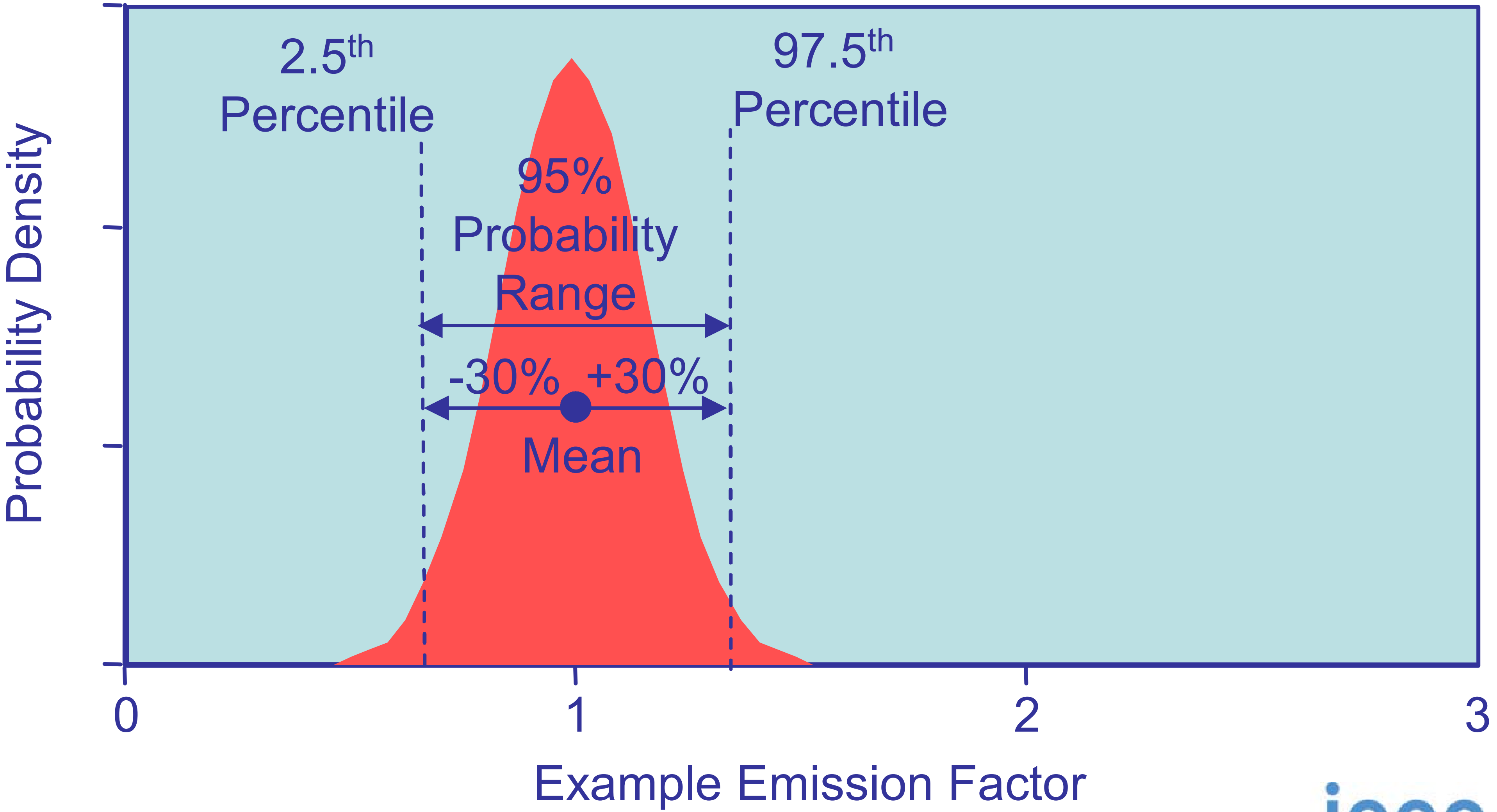
Approach 1 uncertainty calculation

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	$\sqrt{E^2+F^2}$	$\frac{(G\bullet D)^2}{(\sum D)^2}$	Note B	$\left\lvert\frac{D}{\sum C}\right\rvert$	$I\bullet F$	$J\bullet E\bullet\sqrt{2}$	K^2+L^2
		Gg CO_2 equivalent	Gg CO_2 equivalent	%	%	%		%	%	%	%	%
1.A.1. Energy Industries	CH4	35.5346662	32.9951217	5	25	25.50	0.0	3.20506E-05	0.00010495	0.000801264	0.000742109	1.19275E-06
1.A.2. Manufacturing Industries and Constructior	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	[illegible]	[illegible]	54	1.5	-0.005462727	0.023368679	-0.163881819	0.495724537	0.272600067
4.B. Manure Management.	CH4	1903.28061	1199.6	[illegible]	[illegible]	54	0.0	-8.88245E-05	0.003815756	-0.002664735	0.080944413	0.006559099
4.C. Rice Cultivation.	CH4	522.9	33	[illegible]	[illegible]	52	0.0	5.3609E-06	0.001078092	0.000160827	0.015246523	0.000232482
4.F. Field Burning of Agricultural Residues.	CH4	64.3314	3	[illegible]	[illegible]	06	0.0	-1.24107E-05	0.000119565	-0.000372321	0.003381819	1.15753E-05
6.A. Solid Waste Disposal on Land.	CH4	1959.72	373	[illegible]	[illegible]	54	0.4	0.00787088	0.011891742	0.236126385	0.252261939	0.119391756
6.B. Wastewater Handling.	CH4	787.08	747.18	[illegible]	30	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 Constructior	CO2	33991.06	4.34	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	44532.52	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 Constructior	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	-0.01260587	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			∑H	34.6				∑M	11.4670044
					Percentage uncertainty in total inventory:		5.880740472				Trend uncertainty:	3.386296561

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



Probability Density Function

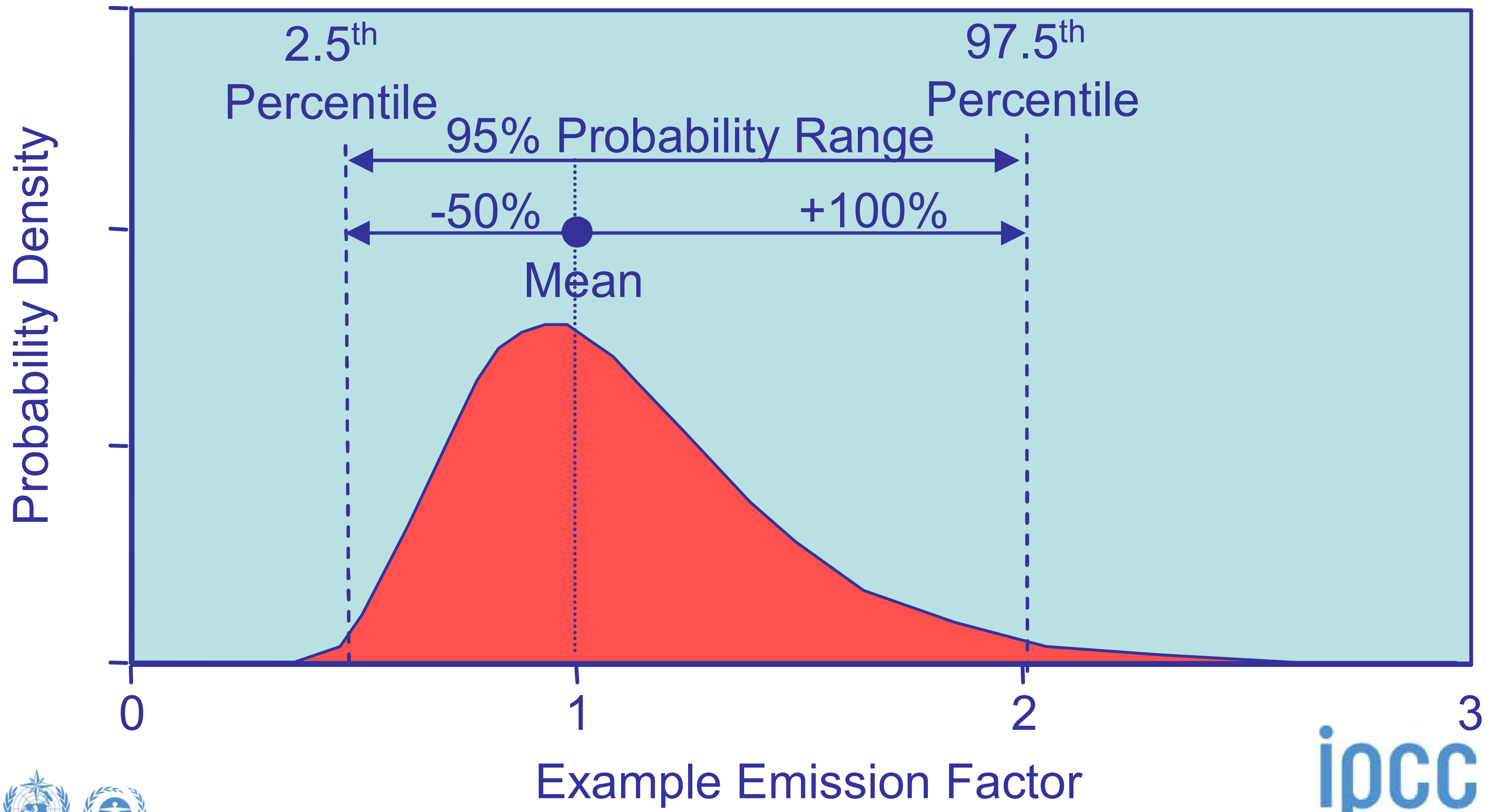
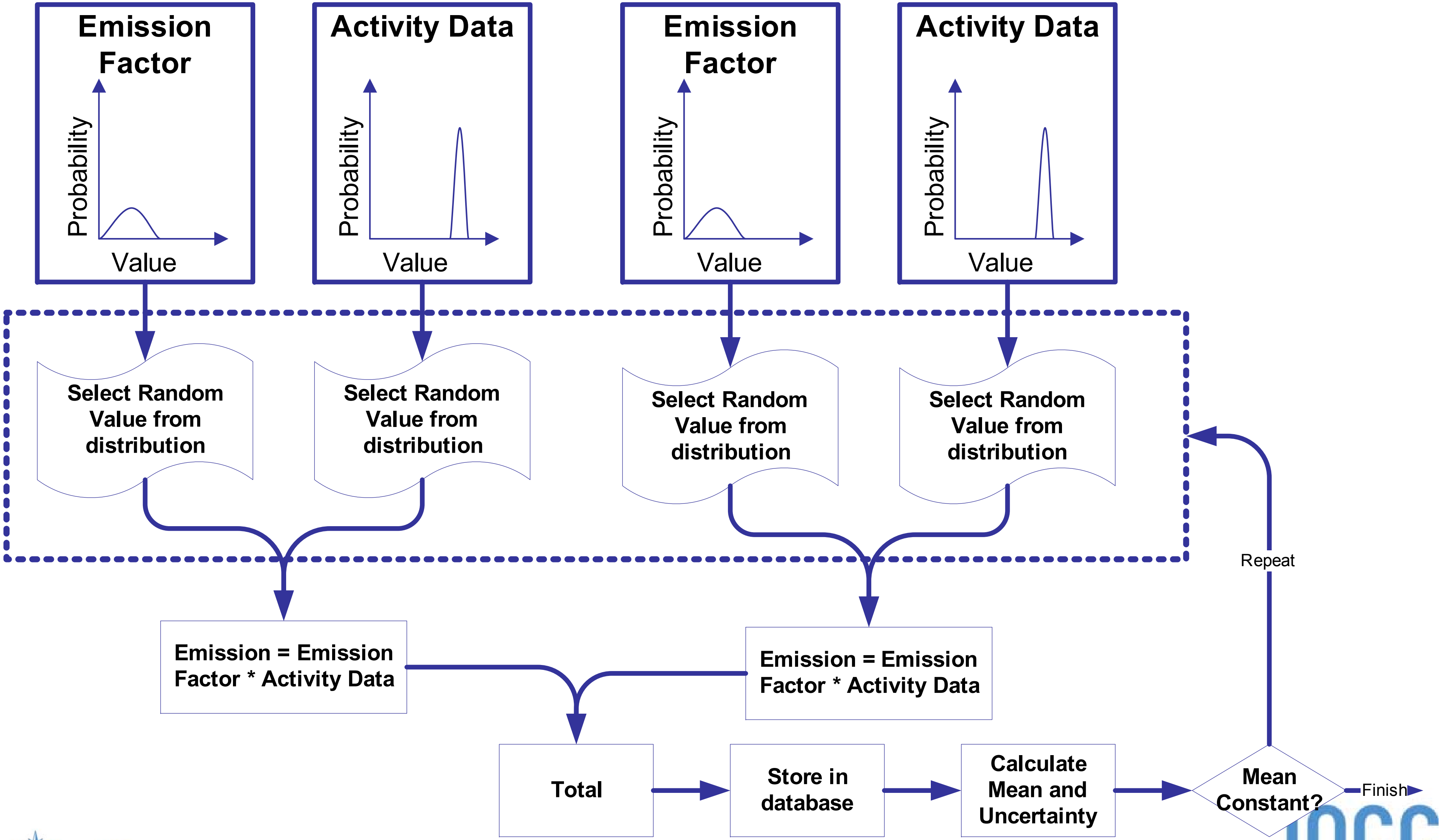
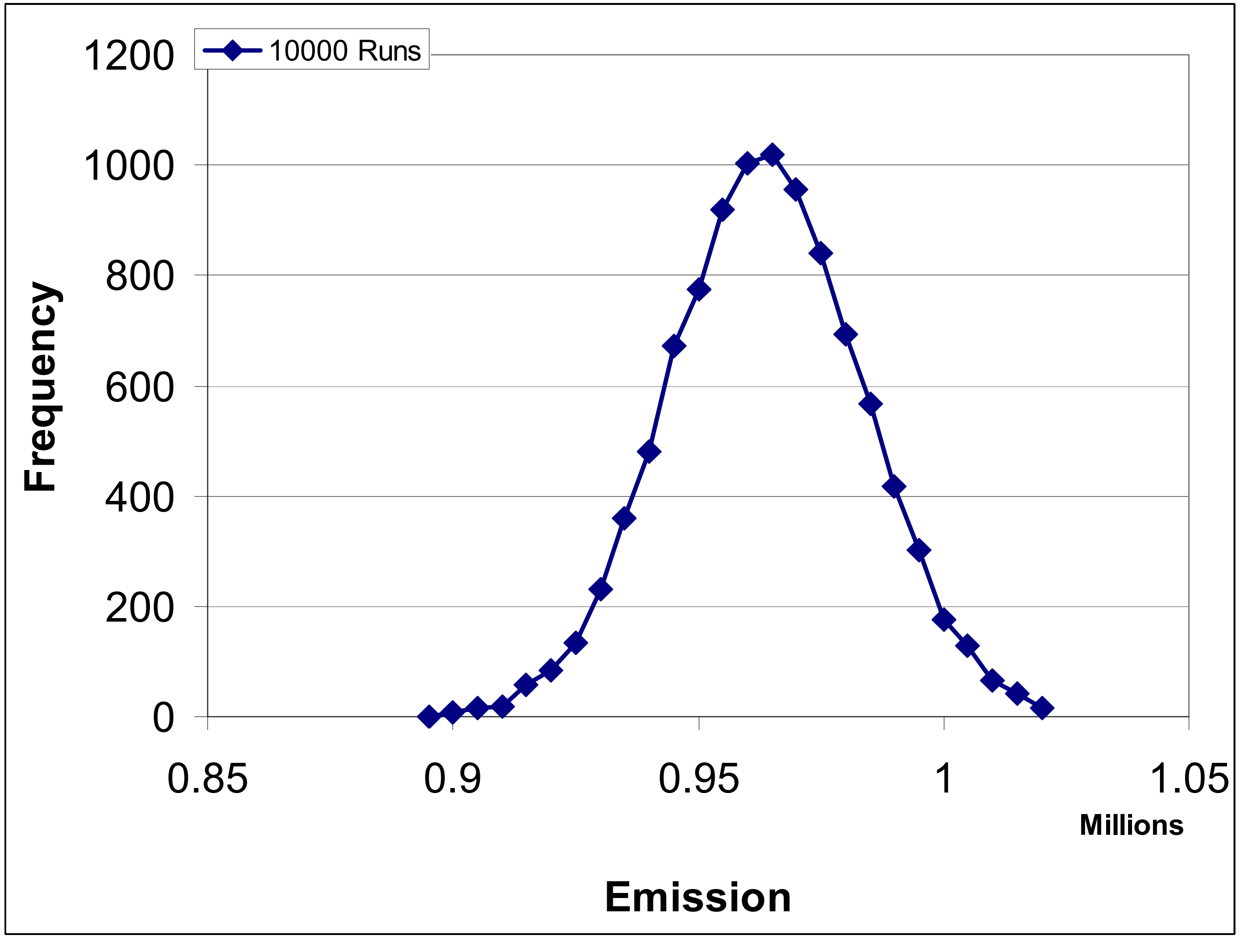


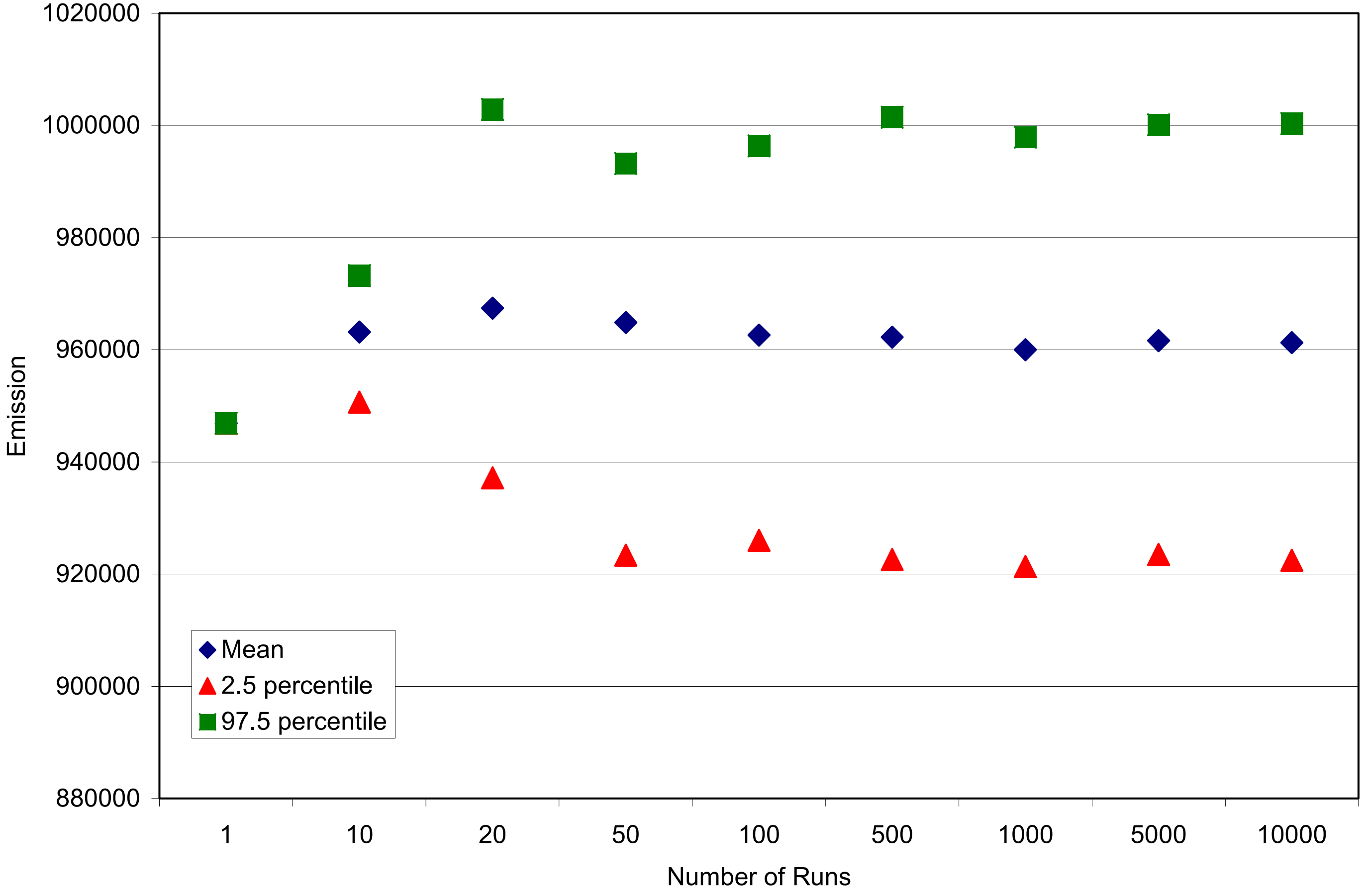
Illustration of Monte-Carlo Method



Example of Monte Carlo Results

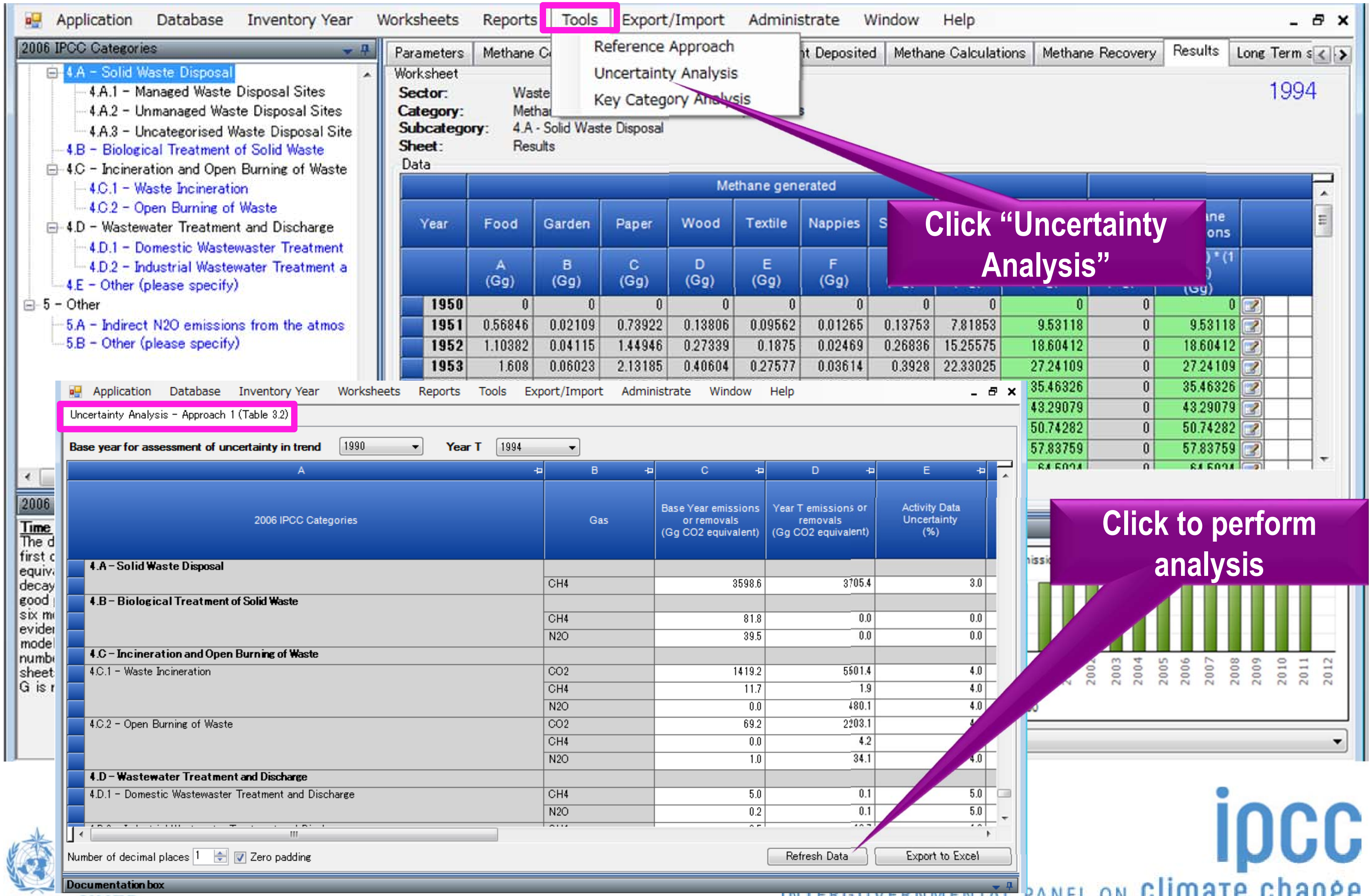


Summary Results



INTERGOVERNMENTAL PANEL ON climate change

Uncertainty Analysis: IPCC Inventory Software



Worksheet

Sector: Waste

Category: Metha

Subcategory: 4.A - Solid Waste Disposal

Sheet: Results

Data

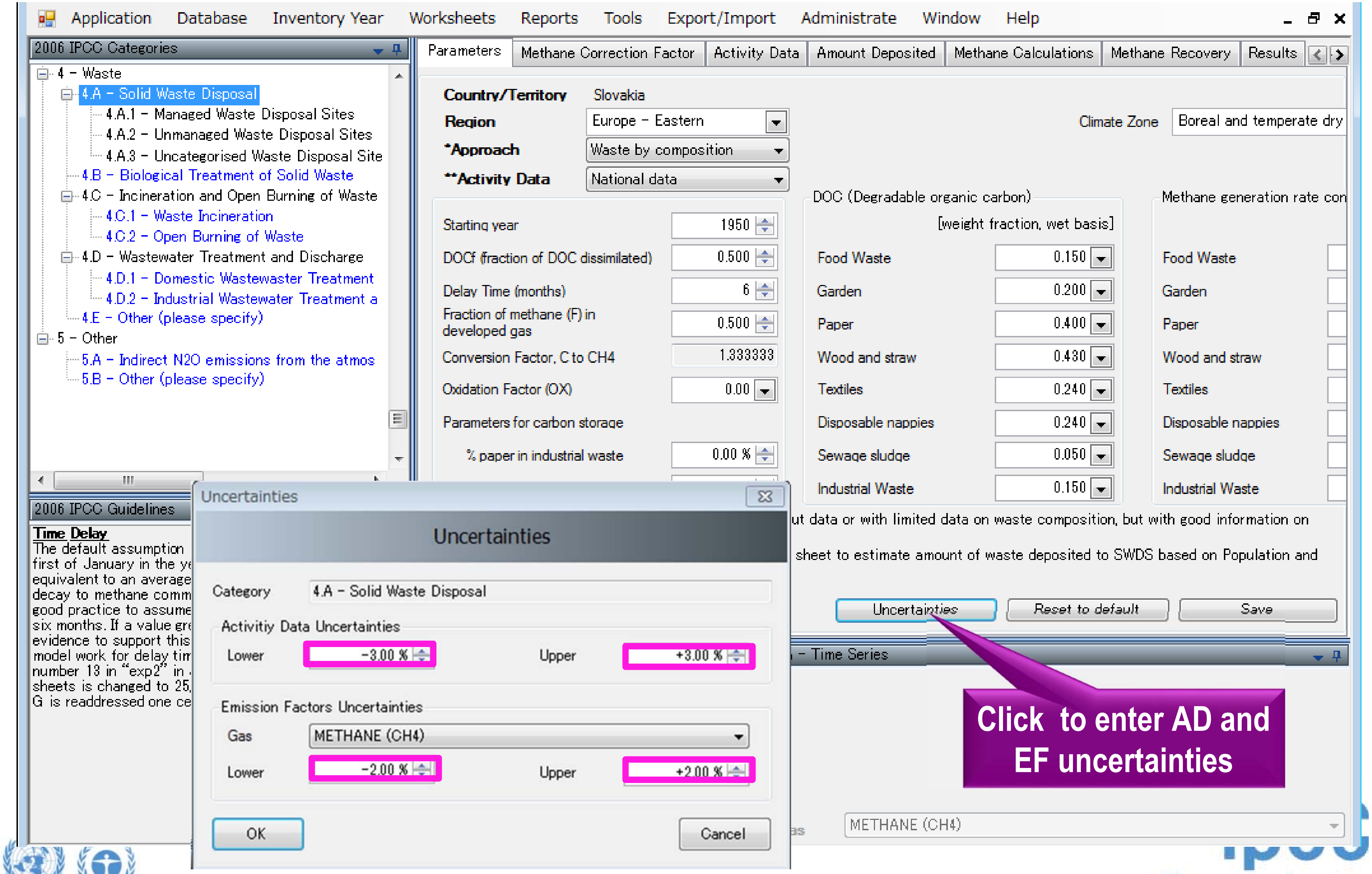
Base year for assessment of uncertainty in trend 1990 **Year T** 1994

A	B	C	D	E
2006 IPCC Categories	Gas	Base Year emissions or removals (Gg CO2 equivalent)	Year T emissions or removals (Gg CO2 equivalent)	Activity Data Uncertainty (%)
4.A – Solid Waste Disposal				
	CH4	3598.6	3705.4	3.0
4.B – Biological Treatment of Solid Waste				
	CH4	81.8	0.0	0.0
	N2O	39.5	0.0	0.0
4.C – Incineration and Open Burning of Waste				
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
	CH4	0.0	4.2	
	N2O	1.0	34.1	4.0
4.D – Wastewater Treatment and Discharge				
4.D.1 - Domestic Wastewaster Treatment and Discharge	CH4	5.0	0.1	5.0
	N2O	0.2	0.1	5.0

Click “Uncertainty Analysis”

Click to perform analysis

Uncertainty Analysis: IPCC Inventory Software (cont.)



Country/Territory Slovakia
Region Europe - Eastern
***Approach** Waste by composition
****Activity Data** National data
Climate Zone Boreal and temperate dry

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]

Food Waste	0.150
Garden	0.200
Paper	0.400
Wood and straw	0.430
Textiles	0.240
Disposable nappies	0.240
Sewage sludge	0.050
Industrial Waste	0.150

Methane generation rate con
Food Waste
Garden
Paper
Wood and straw
Textiles
Disposable nappies
Sewage sludge
Industrial Waste

ut data or with limited data on waste composition, but with good information on
sheet to estimate amount of waste deposited to SWDS based on Population and

2006 IPCC Guidelines
Time Delay
The default assumption
first of January in the ye
equivalent to an average
decay to methane comm
good practice to assume
six months. If a value gre
evidence to support this
model work for delay tim
number 13 in "exp2" in
sheets is changed to 25,
G is readdressed one ce

METHANE (CH4)

Uncertainties

Category 4.A - Solid Waste Disposal

Activitiy 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

WMO UNEP

INTERGOVERNMENTAL PANEL ON climate change

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

Diagrams © IPCC unless otherwise noted