Sectoral Uncertainties in the UK GHG Inventory

Report for DECC

Issue Number 2
Date 14/07/2011

Title	Sectoral Uncertainties in the UK GHG Inventory	
Customer	DECC	
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File reference	n:\naei09\11_improvements\51_communication strategy\uncertaintytask\nc_uncertainties_issue1.docx	
Reference number	ED56595 Issue 1	

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	Date	24.03.2011

Document revision history

Revision history		
Issue	**Version**	**Revision history**
Draft		Reviewed internally
1		Issued to DECC (John Mackintosh)
2		Addition DECC (Jenny Ward)

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1 Introduction

1.1 Purpose of this report

This report presents uncertainties associated with greenhouse gas emissions and removals based on National Communication (NC) sectors[1] and the details of the work needed to generate these data. The NC sectors are used in some DECC statistical releases, and for the UK's carbon budgets. Each NC sector is composed of several IPCC[2] categories, and these categories are used to report GHG emissions and removals in the UK's Greenhouse Gas inventory.

The work builds on the uncertainty analysis conducted for the UK's Greenhouse Gas (GHG) inventory submission to the United Nations Framework Convention on Climate Change (UNFCCC). In the current GHG inventory, estimates are made of the:

- Uncertainty introduced on the national total in 1990, and on the total for the latest reported year, for each of the six Kyoto GHGs;
- Uncertainty on the trend of emissions on a GWP basis; and,
- Uncertainty on total GWP emissions in each major IPCC category (e.g. 1A1) in 1990, and on total GWP emissions in each major IPCC category for the latest reported year.

The reporting of uncertainty on the IPCC categories was introduced in the 2006 National Inventory Report (NIR), and the uncertainties were designed to be indicative only. The work done to generate the uncertainties associated with each NC sector has necessitated making improvements to the method used to generate uncertainties associated with each of the component IPCC categories.

A general summary of the UK uncertainty analysis is contained in Annex 1 to this report, and the full description is presented in Annex 7 of the UK's latest NIR[3].

1.1 What is accuracy, and how accurate should a greenhouse gas inventory be?

A key question is how accurate should a GHG inventory be? If we turn to IPCC guidance, the definitions provided are:

Inventory definition: Accuracy is a relative measure of the exactness of an emission or removal estimate. Estimates should be accurate in the sense that they are systematically neither over nor under true emissions or removals, so far as can be judged, and that uncertainties are reduced so far as is practicable. Appropriate methodologies conforming to guidance on good practices should be used to promote accuracy in inventories. (FCCC/SBSTA/1999/6/Add. 1)

Note that this definition does not make a statement about accuracy with a set tolerance; a key point is the recognition that there will be some uncertainty in the estimates of emissions or removals, and there is an implicit assumption that the effort to improve accuracy (and hence reduce uncertainty) should be proportional to the importance of the source in the inventory now and over time.

Statistical definition: Accuracy is a general term which describes the degree to which an estimate of a quantity is unaffected by bias due to systematic error. It should be distinguished from precision as illustrated in **Figure 1-1** below.

[1] See page 84 of UNFCCC Guidelines contained in FCCC/CP/1999/7 for the definitions of the sectors, available at: http://unfccc.int/resource/docs/cop5/07.pdf

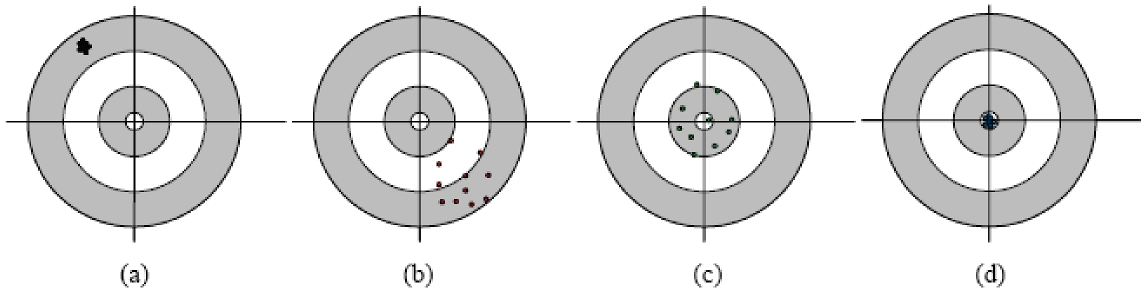
[2] The categories used to report GHG emissions and removals are defined by the Intergovernmental Panel on Climate Change (IPCC), and adopted by the UNFCCC.

[3] The UK's latest NIR with UNFCCC geographical coverage is available here http://ghgi.decc.gov.uk/unfccc.html

It is importance to recognise the difference between accuracy and precision. Ideally, estimates of emissions in the inventory should be both accurate and precise.

Figure 1.1 Difference between accuracy and precision[4]

(a) inaccurate but precise; (b) inaccurate and imprecise; (c) accurate but imprecise; and (d) precise and accurate



The uncertainty assessment is not designed to deal with bias (estimates which are systematically higher or lower than in reality). The assessment improves the precision of the estimate provided. The inventory agency needs to identify bias and if necessary adjust for it. Following the guidelines available to inventory compilers, and following proper QA/QC procedures should eliminate sources of bias, such as omission of certain sources or double counting.

1.2 Why assess uncertainties in GHG inventories?

The UK has signed up to both international agreements (Kyoto Protocol) and domestic targets (the Climate Change Act) for the reduction of emissions of greenhouse gases. Therefore the national GHG inventory is essential to evaluate and demonstrate compliance with these commitments.

Emission inventories will always have some uncertainty. It is not possible to measure directly all the emissions from a country, so inventories are largely based on statistical activity data as well as on emission factors, both of which are subject to uncertainty.

Uncertainties in inventories can be caused by:

- Uncertainties in definitions
- Uncertainties from the natural variability in processes that produce emissions
- Uncertainties from the assessment of the process or quantity (e.g. the amount of fuel) including
    - Measurement uncertainties
    - Sampling uncertainties
    - Reference data uncertainties
    - Uncertainties in expert judgement

Some of these sources of uncertainty should be eliminated through *good practice*[5] in compiling the inventory, such as the uncertainties in definitions since this could affect the completeness of the inventory. For uncertainties that cannot be eliminated, an assessment must be made. This can be made through a statistical analysis of available data, or through expert judgement.

Inventory estimates can be used for a range of purposes. For some purposes, only the national total matters, while for others, the detail by greenhouse gas and source category is important. In order to match the data to the intended purpose, users must be able to understand the actual reliability of both the total estimate and its component parts. This report considers the uncertainty at sector level, and how this compares with the uncertainty in the national total.

Uncertainty estimates are an essential element of a complete emissions inventory. Uncertainty information is not intended to dispute the validity of the inventory estimates, but to help prioritise

[4] Taken from the IPCC 2006 Guidelines
[5] The IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. http://www.ipcc-nggip.iges.or.jp/public/gp/english/

efforts to improve the accuracy of inventories in the future and guide decisions on methodological choice.

Inventory practitioners understand that for most countries and source categories, greenhouse gas emissions estimates are reasonably accurate. However, national inventories will typically contain a wide range of emission estimates, varying from carefully measured and demonstrably complete data on emissions of certain engineered chemicals, to order-of-magnitude estimates of highly variable N_2O fluxes from soils.

1.3 How do we gather the necessary data to support the uncertainty analysis?

The team compiling the UK GHG inventory take a pragmatic approach to producing quantitative uncertainty estimates. We use a combination of the available measured data and expert judgement. The available data is collected through literature review, and through the NAEI/GHG inventory stakeholder consultation programme. The expert judgment is completed by both AEA inventory and UK industry experts and through expert elicitation during discussions with stakeholders.

We have established a programme of review and improvement of the uncertainty analysis. Through this programme we prioritise the sectors where we need to improve the estimates of uncertainty.

It is *good practice* to collect uncertainty information as part of the data acquisition process for the inventory compilation.

2 Estimating uncertainties at National Communication category level

The UK uncertainty model is set up to quantify the uncertainties in the total emissions, by gas. An overview of the model is presented in Annex 1 to this report, and more fully elaborated in Annex 7 of the UK NIR. The analysis presented in this report builds on the analysis carried out for the NIR.

In order to ensure that uncertainties in the national total are not over estimated, it is important to consider correlations between emission sources, both within a given year, and across years. Some of these correlations, whilst important for estimating uncertainties in the national total, will lead to an under estimate in uncertainties at a sectoral level. This is especially important for emissions from fuel use.

2.1 Uncertainties in emissions from fuel combustion

The UK GHG uncertainty model requires an estimate of the uncertainty on each of the fuels used in the UK. The Digest of UK Energy Statistics (DUKES) provides estimates of supply and demand for each of the fuels used in the UK, and this is used to generate the required uncertainty estimates. A simplified description of the method used to process the DUKES data is given below and more detail is given in Annex A.

We assume that the uncertainty in the fuel use may be represented by a normal distribution and calculate a standard deviation from the two estimates of fuel use based on supply and demand. We calculate a coefficient of variation as the standard deviation divided by the mean fuel use. We then assume that the same coefficient of variation applies to all sectors using a given fuel. This coefficient of variation for fuels is referred to as the “statistical difference” in this report and the term is also used in the NIR.

The coefficient of variations and the estimates of the total fuels used are used to generate probability density functions (PDFs) in a Monte Carlo model.

In reality, the estimates of fuel use in each sector are more or less uncertain than this overall coefficient of variation. Taking coal use as an example, the total coal use in the UK is well known, and the statistical difference between supply and demand is small. However, the quality of the estimates of coal used by individual sectors is variable. In some cases, the amounts of coal used are very accurately quantified, for example, in the case of coal fired power stations belonging the European Union Emissions Trading System (EUETS). These stations will carefully monitor the quantities of coal they consume since they must report quantities of fuel burnt as part of their ETS returns. In contrast, the amount of coal used by the domestic and commercial sectors is known much less accurately since it based on more limited data and periodic surveys. The overall total uncertainties of the sectors using coal should not vary by more than the statistical difference in the total coal use.

In order to reflect the additional uncertainty at sector level within the model, a weighting factor has been introduced. This has been calculated by considering the recalculations to the fuel use allocated to each of the sectors between several sequential inventories. These recalculations in fuel use derive in part from changes reported in DUKES. Fuel use allocations within DUKES can be revised from the original estimates for up to three years after their original publication, and sometimes up to five years.

An example for natural gas use allocated to the public sector is detailed below, comparing statistics published in DUKES in 2010, 2009 and 2008. The uncertainty calculated from the statistical difference in total gas use is also presented, for comparison.

Table 2.1 Natural Gas allocated to public administration in DUKES (Mth)

	2006	2007	2008
DUKES 2010	1708.6	1594.6	1600.1
DUKES 2009	1811.4	1664.3	1759.8
DUKES 2008	1811.4	1668.0	N/A
Maximum	1811.4	1668.0	1759.8
Minimum	1708.6	1594.6	1600.1
Difference between maximum and minimum	102.8	73.4	159.8
Standard deviation (SD)	59.4	41.3	113.0
Uncertainty expressed as 2*SD/mean	6.7%	5.0%	13.5%
Uncertainty based on statistical difference	0.2%	0.2%	0.2%

Recalculations to the fuel use allocated to each of the sectors can also occur due to method changes within the inventory as well as due to revisions in energy use statistics (both reported in DUKES and made by the GHG inventory agency team). The weighting factor has been calculated based on inventory recalculations, and therefore includes the impact of both DUKES changes, and method changes for all fuel use sources.

The weighting is applied within the model as an additional PDF for each source and fuel combination. The average of the percentage uncertainty over the years 2006 to 2008 used for both 2009 and 1990. Although the fuel use estimates in 1990 are no longer subject to change due to DUKES revisions, it is still considered that this additional degree of uncertainty would be present in the early part of the time series.

In order to constrain the overall uncertainty to the total implied by the statistical difference in the total fuel use, the sector contributing the most to the use of each of the fuels is calculated by difference from the total within the model.

2.2 Uncertainties in emissions from other sources

Fuel combustion is the only example where correlations in the UK uncertainty model cut across more than one sector. For example, the uncertainty in emissions from natural gas leakage from the gas supply network is assumed to be partially correlated between the base year and the latest inventory year. However, since all emissions from this source are within the energy supply sector, it remains appropriate to retain this correlation within the sectoral uncertainty model.

Therefore in calculating the uncertainties for non-fuel combustion sources, it has been possible to re-aggregate the outputs from the UK uncertainty model into the National Communication categories without further modifying the model.

3 Outputs

Table 3.1 summarises the uncertainties by National Communication category, considering both the uncertainty in the latest inventory year, and the uncertainty in the trend.

Table 3.1 Summary of uncertainties output

NC Category	1990 emissions	2009 emissions	Uncertainty in 2009 emissions	Percentage change between 1990 and 2009	Range of likely % change between 1990 and 2009	
					2.5 percentile	*97.5 percentile*
Energy Supply	272112	195005	1%	-28%	-30%	-27%
Transport	122077	122210	3%	0%	-4%	4%
Residential	80751	78600	2%	-3%	-6%	0%
Business	112388	85851	2%	-24%	-26%	-22%
Public	14069	8206	8%	-42%	-48%	-36%
Industrial Process	54290	10386	6%	-81%	-85%	-77%
Agriculture	63854	49796	185%	-21%	-27%	-14%
Land Use Change	3920	-4149	208%	-301%	-729%	412%
Waste Management	59011	18004	56%	-68%	-83%	-45%
Total	782471	563911	16%	-28%	-31%	-25%

The emission and trend estimates are the central estimates from the model, and are therefore not necessarily exactly the same as the original emissions estimates in the GHG inventory. The 2009 uncertainty percentage is calculated as 2*SD/E, where SD is the standard deviation, and E is the mean output from the model.

3.1 Energy supply

Emissions within the energy supply sector are dominated by CO_2 emissions from fuel combustion. The uncertainty associated with these estimates is low, even at IPCC sectoral level, since the emissions included are from sources such as power stations and refineries, for which there are established reporting systems to capture the data and to apply quality control measures to it. The carbon content of each of the fuels is also well known.

This sector does include a number of more uncertain sources, such as emissions from offshore venting and flaring, but these have a small impact on the total.

The uncertainty introduced on the total emission for this sector in 2009 is 1%. The trend in emissions indicates a decline of 28%, with 95% of the values falling between -30% and -27%.

3.2 Transport

Although emissions from the transport sector are dominated by fuel combustion. In a number of cases the allocation of fuel to the sector is more uncertain. For aviation, the split between domestic and international is calculated within a model, and it is therefore not appropriate to constrain the total fuel use to within an uncertainty range defined by the statistical distance in the total. The same is true for the shipping estimates used within the inventory. Therefore emissions in this sector are less well known than those for energy supply.

The uncertainty introduced on the total emission for this sector in 2009 is 3%. The model outputs show that emissions are about the same magnitude in 1990 as in 2009, with a 95% probability that the trend lies within the range -4% to +4%.

3.3 Residential

Emissions from this sector are dominated by CO_2 emissions from fuel combustion. There have not been any major recalculations to emissions from fuel combustion within this sector, and therefore the additional weighting factors used have had little impact. The uncertainty is higher than for energy supply due to the contribution of emissions of HFCs from aerosols and metered dose inhalers, which account for around 4% of the emission total and are very uncertain.

The uncertainty introduced on the total for this sector in 2009 is 2%. The trend in emissions is a decrease of 3%, with 95% of the values falling between -6% and 0%.

3.4 Business

Most of the emissions from this sector relate to fuel combustion. The analysis of recalculation revealed that only the smaller emission sources have undergone major recalculations, and as such the impact on the uncertainty total has been small. This sector also includes some emissions of HFCs, which are relatively more uncertain than estimates for fuel combustion, leading to a higher uncertainty than for energy supply.

The uncertainty introduced on the total for this sector in 2009 is 2%. The trend in emissions is a decrease of 24%, with 95% of the values falling between -26% and -22%.

3.5 Public

Emissions from public administration are predominantly CO_2 emissions from the combustion of fuels. As noted in Section 2.1, at a national total level, CO_2 emissions by fuel are relatively certain. However, the fuel use allocation to this sub sector has been subject to significant recalculations, and we consider this feature to be an indication of the inherent difficulties of accurately estimating fuel consumptions in this sector.

Therefore the estimated uncertainty on the total emission for this sector in 2009 is 8%. This is higher than other sources where the allocations of fuel use are more certain. The trend in emissions is a decrease of 42% with 95% of the values falling between -48% and -36%.

3.6 Industrial Processes

For the industrial processes sector, the uncertainty in the emission estimate has decreased significantly from 1990 to 2009, since emission estimates from the more uncertain emission sources (e.g. nitric and adipic acid production) have decreased, and in some cases become less uncertain. In 2009, almost half of the emissions were from cement production and sinter production, both of which are amongst the least uncertain sources within the sector. The uncertainty in 1990 was estimated at 28%, compared with 6% in 2009.

The trend in emissions is a decrease of 81%, with 95% of the values falling between -85% and -77%.

3.7 Land Use, Land Use Change and Forestry

The uncertainty introduced on the sector total for Land Use, Land Use Change and Forestry (LULUCF) is expressed as a percentage of the absolute magnitude of the emissions in 2009. It has been necessary to use an absolute function to accommodate the sinks of CO_2 in this sector, where removals of CO_2 from the atmosphere are reported with a negative sign.

Emissions from this sector are very uncertain, and no correlations between sources within a given year are considered within the model. Correlations between the same sources across years are considered, but since there is not one source which dominates the overall trend, and because each of the sector estimates are very uncertain, the uncertainty in the emissions in a given year, and in the trend is high.

The uncertainty introduced on the total for this sector in 2009 is 208%. The trend in emissions is a decrease of 301%, with 95% of the values falling between -729% and +412%.

It should be noted that, although the uncertainty on the emission in 2009 is high, and the trend is highly uncertain, the overall magnitude of this sector is small and therefore the impact on the overall uncertainty of the inventory is also small.

3.8 Agriculture

Emissions from agriculture are highly uncertain, and this is driven by the uncertainty in the emission factor for agricultural soils. This emission factor is, however, correlated between years, which acts to reduce the uncertainty on the trend.

The uncertainty introduced on the total for this sector in 2009 is 185%. The trend in emissions is a decrease of 21%, with 95% of the values falling between -27% and -14%.

3.9 Waste management

Both the emissions and the uncertainty within the waste management sector are dominated by the uncertainty in the emissions estimate for landfill. This is calculated using a custom distribution, and is considered to be partially correlated between 1990 and the latest inventory year.

The uncertainty introduced on the total for this sector in 2009 is 56%. The trend in emissions is a decrease of 68%, with 95% of the values falling between -83% and -45%.

Annex 1: The UK GHGI uncertainty model

The UK GHG inventory uses two approaches to assess uncertainty: an error propagation method, and a more complex Monte Carlo model. The UK bases its uncertainty analyses on IPCC guidance. The analysis presented in this report is based on the Monte Carlo model.

Estimation of Uncertainty by Simulation (Approach 2)

Quantitative estimates of the uncertainties in the emissions are also calculated using Monte Carlo (MC) simulation. This corresponds to an IPCC Tier 2 approach discussed in the Good Practice Guidance (IPCC, 2000), or Approach 2 in the IPCC 2006 Guidelines. The background to this work is described in detail by Eggleston *et al* (1998). This section gives a brief summary of the methodology, assumptions and results of the simulation.

The computational procedure is:

- A probability distribution function (PDF) is allocated to each unique emission factor and piece of activity data. The PDFs are mostly normal, with some log-normal distributions used. The parameters of the PDFs were set by analysing the available data on emission factors and activity data or by expert judgement.
- A calculation has been set up to estimate the total emissions of each gas and carbon dioxide sink, and the global warming potential for the years 1990, the base year[6], and the latest year reported.
- Using the software tool @RISK™, each PDF is sampled 20,000 times and the emission calculations performed to produce a sample distribution which we assume is very close to a converged output distribution.
- The quoted range of possible error of uncertainty is taken as 2s, where s is the standard deviation. If the expected value of a parameter is E and the standard deviation is s, then the uncertainty is quoted as 2s/E expressed as a percentage. For a normal distribution the probability of the parameter being less than E-2s is 0.025 and the probability of the emission being less than E+2s is 0.975.
- The uncertainties used for the fuel activity data are estimated from the statistical difference between supply and demand for each fuel. This means that the quoted uncertainty refers to the total fuel consumption rather than the consumption by a particular sector, e.g. residential coal. Hence, to avoid underestimating uncertainties, it is necessary to correlate the uncertainties used for the same fuel in different sectors. Where possible, emissions data have been correlated by fuel activity in order to minimise underestimation as far as possible.
- The uncertainty in the trend between 1990 and the most recent inventory year quoted, according to gas, is also estimated. Correlations between years are important to consider within the uncertainty analysis; the model is sensitive to the inclusion or exclusion of these.

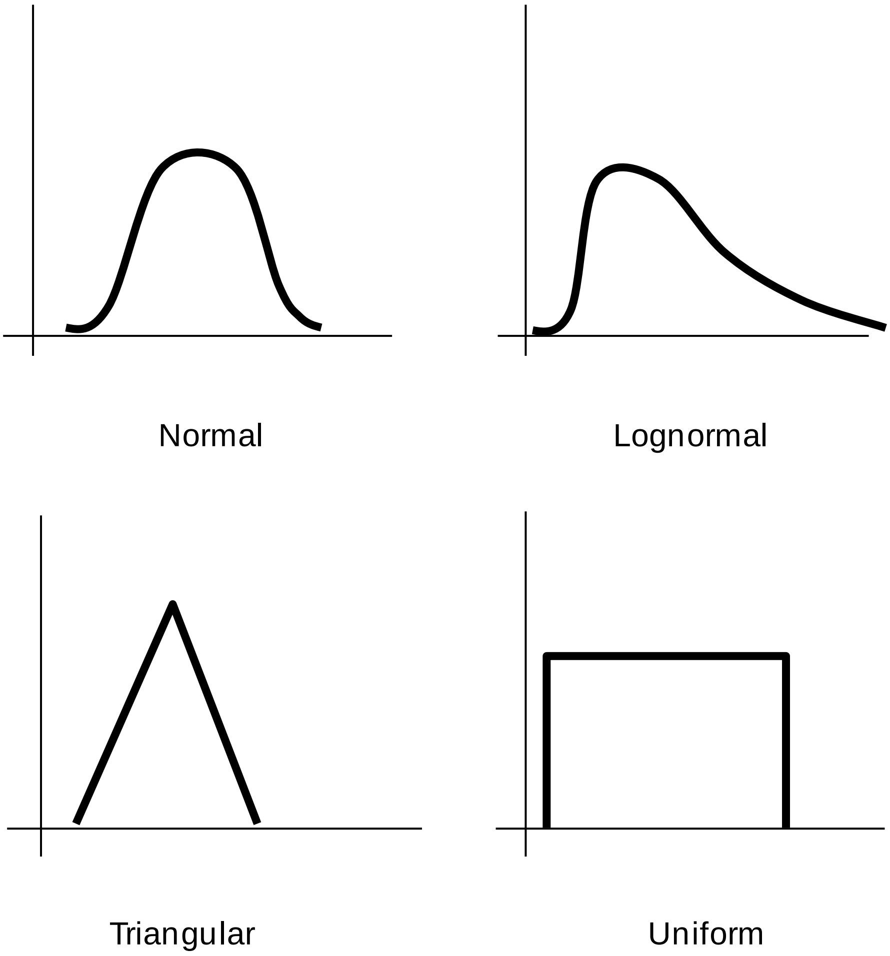
Figure 2.2 below shows four types of distribution that can be used in an MC simulation (normal, lognormal, uniform, and triangular). The choice of distribution depends on how much is known about the emission or other parameter, and the range of the 95% confidence interval.

For example, a triangular distribution can be used where an expert is able to identify a preferred value, and an upper and lower limit (this does not have to be symmetrical). A uniform distribution is usually used where only the range within which the value is likely to fall is known, but there is no preferred value within that range. A normal distribution is used where the uncertainty is low, and is symmetrical around the central estimate. For parameter where the uncertainty is very high, but the value cannot be below zero, a lognormal distribution is used.

In the UK inventory uncertainty analysis, only normal and lognormal distributions are used.

[6] These 'base year' emissions **are not** those calculated as part of the assessment towards the Kyoto target as the emissions do not include adjustments for Articles 3.3, 3.4 or 3.7. The 'base year' in this case is calculated as total emissions of CO_2, CH_4 and N_2O in 1990, and emissions of the F-Gases in 1995.

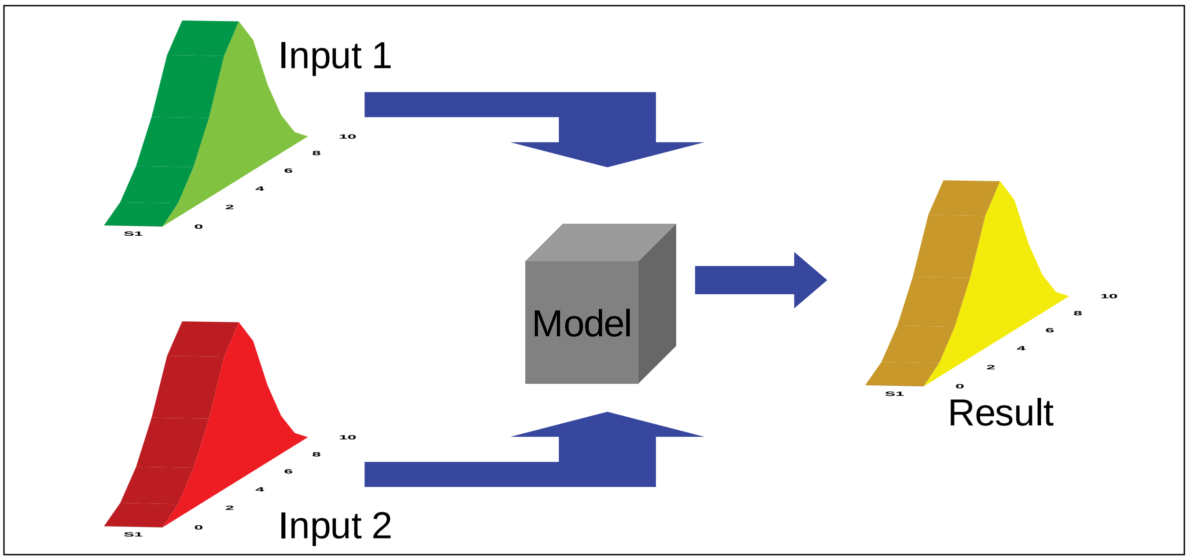
Figure 3.1 Types of uncertainty distributions



Overview of using the MC method

Conceptually, the MC model combines several PDFs to produce a composite PDF (see **Figure 3.2**). The PDFs may be independent of each other, or there may be correlations between them. These correlations can make a large difference to the overall uncertainty assessment.

Figure 3.2 Illustration of combining PDFs



The Monte Carlo modelling approach taken in the UK inventory can be broken down in three main steps.

In **Step 1**, the component uncertainties are assessed. Estimates of uncertainties might be available for both activity data and emission factors or only for total emissions where the emissions are generated from complex models (such as carbon fluxes in the LULUCF sector from the C-Flow model). If such models are used, then it may only be possible to assess uncertainty at relatively high IPCC sector levels (such as 5A, 5B etc.) rather than in all the specific activities that are used to derive the overall estimate of emissions. When the MC model is created, it is important to assess the correlations between the sources. **Table 3.2** provides some examples of where activity data and emission factors are not independent:

Table 3.2 Examples where correlations need to be introduced in the MC model

Situation	Example
Activity Data are calculated via mass balance	Supply and demand of fuels in energy statistics
Emission Factors are shared across activities	Natural gas or gas/diesel oil used by different sources
Emission Factors are shared across a time series	N_2O from agricultural soils

In **Step 2**, the MC model is run 20,000 times in order to produce a sample distribution which we assume is very close to a converged output distribution.

In **Step 3**, the output from the MC model is processed in order to provide the uncertainties by gas for given years (1990, the base year, and the latest reported inventory year) and according to sector for the latest reported inventory year.

Comparative uncertainty in an inventory for a given year and in the trend

The largest single emission component for most countries - carbon dioxide from fossil fuel combustion - is known relatively accurately. This is the case for the UK. However the overall uncertainty in the total emissions estimate for a particular year could certainly be greater than present reduction commitments of 5-10% for Annex I countries. The uncertainty on the trend between years (as a percentage change) is likely to be less than the uncertainty in a given year and this is because the same methodology has to be used for the base year and the commitment period.

Thus an emissions inventory might be accurate enough for showing compliance with percentage reduction targets, where it is the trend that is important.

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