9

The Uncertainty Estimation and Use of Measurement Units in National Inventories of Anthropogenic Emission of Greenhouse Gas

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1. Introduction

A global policy for environmental protection is needed and is under discussion. One of the effects of modern global policy for environmental protection includes the multitude of measurements that are part of the process of environment protection, including the estimation of greenhouse gas (GHG) emission. Global climate studies bring together an enormous range of sciences and for a sound model to be developed it is necessary that the data from all these areas be comparable. The only way for this to be assured is for measurements in all areas of science to be made in terms of a well-defined system of units, namely the International System of Units (SI).

Human activities to have major impacts on the global climate change which caused by an increase of GHG in the atmosphere. In general, there is now a demand for people to have confidence in the credibility of the results of measurements because in so many ways decisions based on the data that come from measurements are increasingly seen to have a direct influence on the economy, human health and safety, and welfare. The United Nations (UN) and its member states adopted the UN Framework Convention on Climate Change (UNFCCC). Parties of the UNFCCC must estimate GHG anthropogenic emissions and to develop annual national GHG inventories.

The governing bodies of the World Meteorological Organization (WMO) and of the UN Environment Programme (UNEP) created a body, the Intergovernmental Panel on Climate Change (IPCC), to marshal and assess scientific information on the subject. For monitoring of global climate change and providing reliable data for climate modelling, a Global Atmospheric Watch (GAW) programme has started by the WMO. The UNFCCC is also starting probably the largest environmental monitoring programme in the world. Parties of UNFCCC can estimate GHG emissions in using two general approaches: direct measurement or proxy data (Velychko O. & Gordiyenko T., 2007a, 2011).

Today's global economy depends on reliable measurements and tests, which are trusted and accepted internationally. Metrology is the scientific study of measurement. Measurements have always been essential in supporting international trade and regulation. Metrology delivers the basis for the comparability of test results, e. g. by defining the units of the measurement and by providing traceability and associated uncertainty of the measurement results. Measurement results may be used provided that the corresponding characteristics of measurement uncertainty are known.

The tasks of the Joint Committee for Guides in Metrology (JCGM) are to maintain and promote the use of the Guide to the Expression of Uncertainty in Measurement (known as the GUM) and the International Vocabulary of Metrology (known as the VIM). The JCGM has taken over responsibility for these two documents, who originally published them under the auspices of the International Bureau of Weights and Measures (BIPM), the International Organization of Legal Metrology (OIML), the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC), the International Federation of Clinical Chemistry and Laboratory Medicine (IFCC), the International Union of Pure and Applied Chemistry (IUPAC), the International Union of Pure and Applied Physics (IUPAP), the International Laboratory Accreditation Cooperation (ILAC).

The General Conference on Weights and Measures (CGPM) adopted SI, for the recommended practical system of units of measurement. The nearly universal use of the SI has brought coherence to all scientific and technological measurements, a worldwide consensus on the evaluation and expression of uncertainty in measurement would permit the significance of a vast spectrum of measurement results in science, engineering, commerce, industry, and regulation to be readily understood and properly interpreted. Many of the quantities, their recommended names and symbols, and the equations relating them, are listed in the international standards ISO/IEC 80000, in which it is proposed that the quantities and equations used with the SI. The IUPAP recognizes the SI for expressing the quantitative results of measurements in physics. The IUPAC serves to advance the worldwide aspects of the chemical sciences and to contribute to the application of chemistry in the service of Mankind (Velychko O. & Gordiyenko T., 2007a, 2010).

Some metrological terms are used in special guides of the IPCC, which to use for preparation of national inventories of GHG. Therefore it is important to compare uncertainty estimation with international ecological and metrological guides, and to consider peculiarities of their using also. It is also important to consider peculiarities of SI units used in those ecological guides.

2. The use metrological terms in international environmental guides

All branches of science and technology need to choose their vocabulary with care. Each term must have the same meaning for all of its users. In order to try and resolve this problem in field of metrology at an international level, eight international organizations developed VIM. The IPCC and the UNFCCC resolved this problem in environmental field.

Throughout the review process, it is asked to assess the quality of the each Party's UNFCCC national inventory submission, with quality being determined by criteria (TACCC – Fig. 1):

transparency (disclosing sufficient and appropriate GHG-related information to allow intended users to make decisions with reasonable confidence); *accuracy* (reducing bias and uncertainties as far as is practical); *completeness* (including all relevant GHG emissions and removals); *consistency* (enabling meaningful comparisons in GHG-related information) and *comparability* (estimates of emissions and removals reported by countries in inventories should be comparable among countries) (ISO 14064-1…3, IPCC 2006). For this purpose, countries should use agreed methodologies and formats for estimating and reporting national inventories.

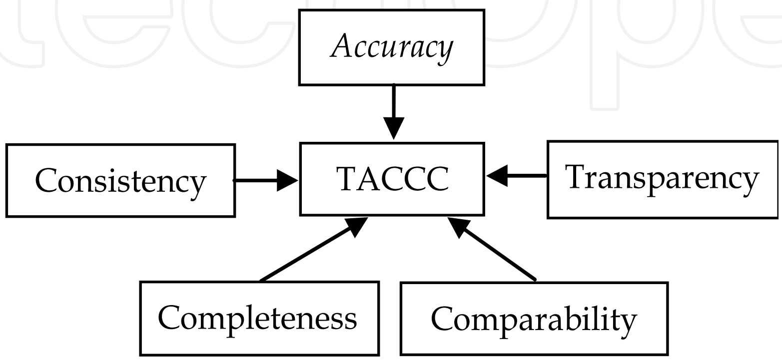

Fig. 1. The TACCC criteria

Definitions associated with conducting an uncertainty analysis include *accuracy*, *precision*, *uncertainty*, and *error* are described in GPG 2000, IPCC 2006, ISO 14064-1…3, VIM 2007, ISO 5725-1, ISO 3534-1 (Velychko O. & Gordiyenko T., 2005, 2007a, 2007b). Comparison of same metrological (and some statistical) and environmental guides and international standards terms are provided in Table 1.

Metrological terms	**Environmental terms**
Accuracy: closeness of agreement between a measured quantity value and a true quantity value of a measurand (VIM 2007); closeness of agreement between a test result and the accepted reference value (ISO 5725-1, ISO 3534-1).	*Accuracy*: a general term which describes the degree to which an estimate of a quantity is unaffected by bias due to systematic error (GPG 2000); a relative measure of the exactness of an emission or removal estimate (IPCC 2006); reducing bias and uncertainties as far as is practical (ISO 14064-1…3).
Precision: closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions (VIM 2007); the closeness of agreement between independent test results obtained under stipulated conditions (ISO 5725-1, ISO 3534-1)	*Precision*: the inverse of uncertainty in the sense that the more precise something is, the less uncertain it is (GPG 2000); closeness of agreement between independent results of measurements obtained under stipulated conditions (IPCC 2006).

Metrological terms	**Environmental terms**
Uncertainty: non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used (VIM 2007); an estimate attached to a test result which characterizes the range of values within which the true value is asserted to lie (ISO 5725-1, ISO 3534-1).	*Uncertainty*: an uncertainty is a parameter, associated with the result of measurement that characterises the dispersion of the values that could be reasonably attributed to the measured quantity (GPG 2000); lack of knowledge of the true value of a variable that can be described as a probability density function characterizing the range and likelihood of possible values (IPCC 2006); parameter associated with the result of quantification which characterizes the dispersion of the values that could be reasonably attributed to the quantified amount (ISO 14064-1…3).
Error: measured quantity value minus a reference quantity value (VIM 2007); the test result minus the accepted reference value (of the characteristic), which is the sum of random errors and systematic errors (ISO 5725-1, ISO 3534-1).	*Error*: a general term referring to the difference between an observed (measured) value of a quantity and its “true” (but usually unknown) value and does not carry the pejorative sense of a mistake or blunder (GPG 2000).
Systematic error: component of measurement error that in replicate measurements remains constant or varies in a predictable manner (VIM 2007); a component of the error which, in the course of a number of test results for the same characteristic, remains constant or varies in a predictable way (ISO 5725-1, ISO 3534-1).	*Systematic error*: the difference between the true, but usually unknown, value of a quantity being estimated, and the mean observed value as would be estimated by the sample mean of an infinite set of observations (GPG 2000, IPCC 2006).
Random error: component of measurement error that in replicate measurements varies in an unpredictable manner (VIM 2007); a component of the error which, in the course of a number of test results for the same characteristic, varies in an unpredictable way (ISO 5725-1, ISO 3534-1).	*Random error*: the random error of an individual measurement is the difference between an individual measurement and the above limiting value of the sample mean (GPG 2000, IPCC 2006).

Metrological terms	**Environmental terms**
Coverage interval: interval containing the set of true quantity values of a measurand with a stated probability, based on the information available (VIM 2007).	*Confidence interval*: the range in which it is believed that the true value of a quantity lies (GPG 2000); the true value of the quantity for which the interval is to be estimated is a fixed but unknown constant, such as the annual total emissions in a given year for a given country (IPCC 2006).
Covariance: means of the mutual dependence of two random variables (GUM 1993).	*Covariance*: a measure of the mutual dependence between two variables (GPG 2000).
Correlation: the relationship between two or several random variables within a distribution of two or more random variables (ISO 3534-1).	*Correlation*: mutual dependence between two quantities (GPG 2000, IPCC 2006).
Correlation coefficient: measure of the relative mutual dependence of two variables, equal to the ratio of their covariances to the positive square root of the product of their variances (GUM 1993).	*Correlation coefficient*: a number laying between –1 and +1 which measures the mutual dependence between two variables which are observed together (GPG 2000, IPCC 2006).

Table 1. Metrological and environmental guides and international standard terms

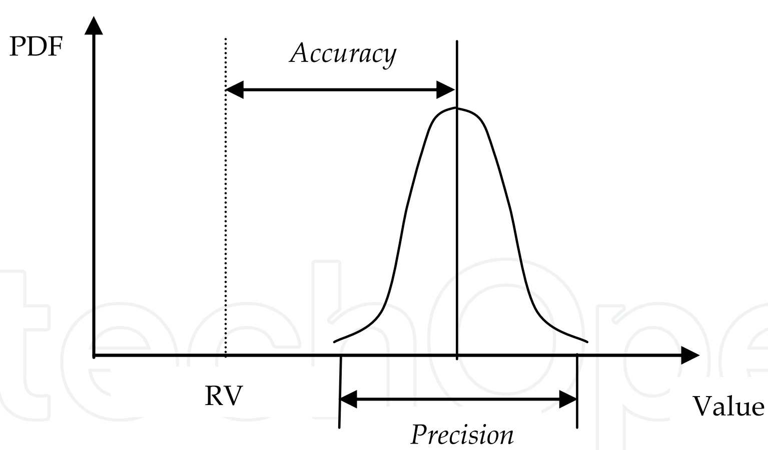

Fig. 2. Relationship between accuracy and precision

The *accuracy* and *precision* of individual measurements will depend upon the equipment and protocols used to make the measurements. A measurement system (equipment) is designated valid if it is both *accurate* and *precise*. The relationship between accuracy and precision is shown in Fig. 2 (PDF is probability density function; RV is reference value).

The concept "*measurement accuracy*" is not a quantity and is not given a numerical quantity value (VIM 2007). The term *accuracy*, when applied to a set of test results, involves a combination of random components and a common systematic error or bias component (ISO 5725-1, ISO 3534-1). 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 (IPCC 2006).

Accepted reference value is a value that serves as an agreed-upon reference for comparison, and which is derived as: a theoretical or established value, based on scientific principles; an assigned or certified value, based on experimental work of some national or international organization; a consensus or certified value, based on collaborative experimental work under the auspices of a scientific or engineering group; when the first three are not available, the expectation of the (measurable) quantity, i.e. the mean of a specified population of measurements.

Measurement precision is usually expressed numerically by measures of imprecision, such as standard deviation, variance, or coefficient of variation under the specified conditions of measurement (VIM 2007). *Precision* is the inverse of uncertainty in the sense that the more precise something is, the less uncertain it is (IPCC 2006).

Precision depends only on the distribution of random errors and does not relate to the true value or the specified value. The measure of precision usually is expressed in terms of imprecision and computed as a standard deviation of the test results. Less precision is reflected by a larger standard deviation. “Independent results” means results obtained in a manner not influenced by any previous result on the same or similar test object. Quantitative measures of precision depend critically on the stipulated conditions (ISO 3534-1). The relationship between small or large accuracy and precision is shown in Fig. 3.

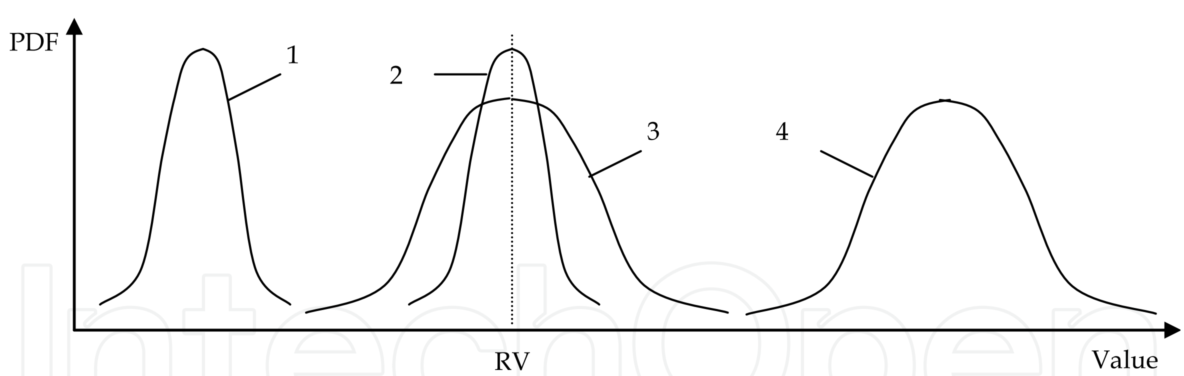

Fig. 3. Small or large accuracy and precision (1-small accuracy and large precision; 2-large accuracy and large precision; 3-large accuracy and small precision; 4-small accuracy and small precision)

The parameter (for uncertainty) may be, for example, a standard deviation called standard measurement uncertainty (or a specified multiple of it), or the half-width of an interval, having a stated coverage probability. In general, for a given set of information, it is understood that the measurement uncertainty is associated with a stated quantity value attributed to the measurand (VIM 2007).

Uncertainty of measurement comprises, in general, many components. Some of these components may be estimated on the basis of the statistical distribution of the results of a series of measurements and can be characterized by *standard deviations*. Estimates of other components can only be based on experience or other information (ISO 3534-1).

Uncertainty depends on the analyst's state of knowledge, which in turn depends on the quality and quantity of applicable data as well as knowledge of underlying processes and inference methods (IPCC 2006). Uncertainty information typically specifies quantitative estimates of the likely dispersion of values and a qualitative description of the likely causes of the dispersion (ISO 14064-1…3).

Uncertainty should be distinguished from an estimate attached to a test result which characterizes the range of values within which the expectation is asserted to lie. This latter estimate is a measure of precision rather than of accuracy and should be used only when the true value is not defined. When the expectation is used instead of the true value the expression "random component of uncertainty" should be used.

Systematic measurement error, and its causes, can be known or unknown. A correction can be applied to compensate for a known systematic measurement error. *Random measurement errors* of a set of replicate measurements form a distribution that can be summarized by its expectation, which is generally assumed to be zero, and its variance (VIM 2007).

Error of result is the test result minus the accepted RV (of the characteristic). Error is the sum of systematic and random errors. *Systematic error* may be known or unknown; *random error* it is not possible to correct (ISO 3534-1).

The relationship between error and uncertainty is shown in Fig. 4 (GUM 1993).

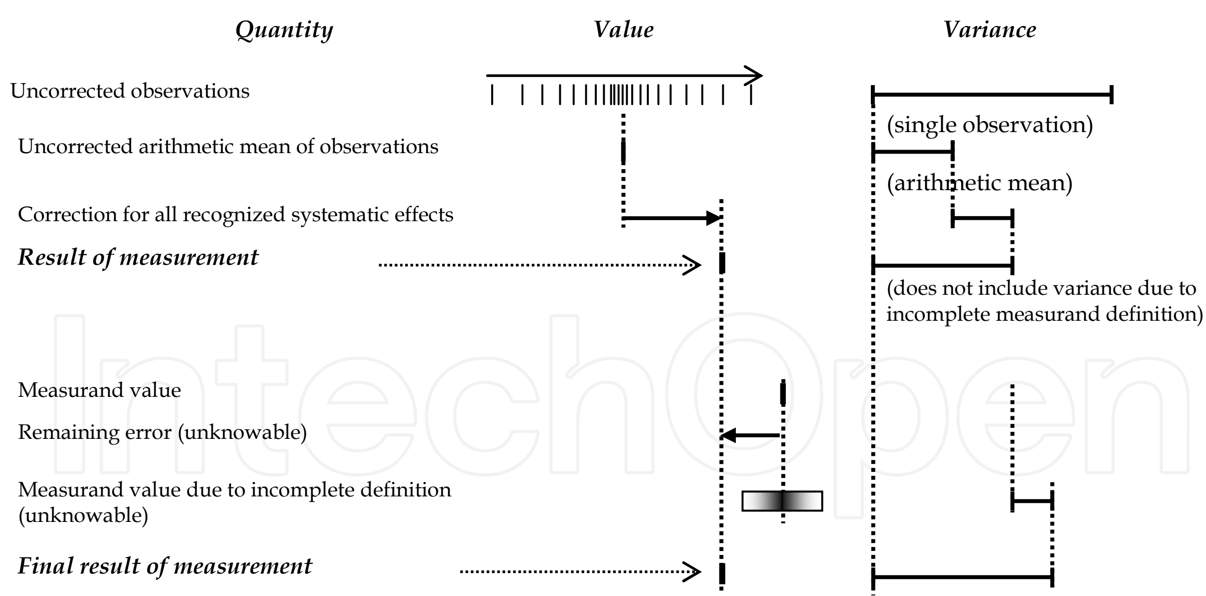

Fig. 4. Relationship between error and uncertainty

To express of the measurement result is used the expanded measurement uncertainty with a specified coverage interval which does not need to be centred on the chosen measured quantity value. This interval should not be termed "confidence interval" to avoid confusion with the statistical concept and can be derived from an expanded measurement uncertainty (GUM 1993, VIM 2007).

The level of belief is expressed by the probability, whose value is related to the size of the interval. It is one of the ways in which uncertainty can be expressed. In practice a confidence interval is defined by a probability value, say 95%, and confidence limits on either side of the mean value x. In this case the confidence limits would be calculated from the PDF such that there was a 95% chance of the true value of the quantity being estimated by x lying between those limits. Commonly limits are the 2.5 percentile and 97.5 percentile respectively (GPG 2000).

The *confidence interval* is a range that encloses the true value of this unknown fixed quantity with a specified confidence (probability). Typically, a 95 % confidence interval is used in greenhouse gas inventories. From a traditional statistical perspective, the 95 % confidence interval has a 95 % probability of enclosing the true but unknown value of the quantity. An alternative interpretation is that the confidence interval is a range that may safely be declared to be consistent with observed data or information. The 95 %confidence interval is enclosed by the 2.5^{th} and 97.5^{th} percentiles of the PDF (IPCC 2006).

Dependencies among input sources will matter only if the dependencies exist between two sources to which the uncertainty in the GHG national inventory is sensitive and if the dependencies are sufficiently strong. For the quantities evaluation of dependence of two or more input sources used the correlation coefficient.

A value of +1 of *correlation coefficient* means that the variables have a perfect linear relationship; a value of –1 of correlation coefficient means that there is a perfect inverse linear relation; and a value of 0 of correlation coefficient means that there is no straight line relation. It is defined as the covariance of the two variables divided by the product of their *standard deviations* (σ). The population standard deviation is the positive square root of the variance. It is estimated by the sample standard deviation that is the positive square root of the sample variance (GPG 2000, IPCC 2006).

For the preparation of GHG national inventories used the activity data (AD) and emission factor (EF). *Activity data* is data on the magnitude of a human activity resulting in emissions or removals taking place during a given period of time. Data on energy use, metal production, land areas, management systems, lime and fertilizer use and waste arisings are examples of AD. *Emission factor* is a coefficient that quantifies the emissions or removals of a gas per unit activity. EF is often based on a sample of measurement data, averaged to develop a representative rate of emission for a given activity level under a given set of operating conditions (IPCC 2006).

3. Uncertainty estimation in international environmental and metrological guides

Parties of UNFCCC can estimate GHG emissions in using two general approaches: direct measurement or proxy data. The concept of uncertainty in direct measurements is more consistent with a statistical concept of uncertainty. The statistical issues include precision and calibration of measurement equipment, fraction of population captured, frequency of sampling, etc. In contrast, proxy data is more typically in the form of AD and EF. The proxy data approach requires assumptions as to the relationship between some activity and actual emissions (IPCC 2006).

GHG emissions can be measured either directly or indirectly. The indirect approach usually involves the use of an estimation model (e.g., AD and an EF), while the direct approach requires that emissions to the atmosphere be measured directly by some form of instrumentation (e.g., continuous emissions monitor). As the data used in the direct or indirect measurement of GHG emissions are subject to random variation there is always statistical uncertainty associated with the resulting emission estimates.

The uncertainty in this relationship must be considered as well as the accuracy and precision in measurements in the proxy data itself. An uncertainty is a parameter, associated with the result of measurement that characterizes the dispersion of the values that could be reasonably attributed to the measured quantity (GPG 2000). An *uncertainty analysis* of a model aims to provide quantitative measures of the uncertainty of output values caused by uncertainties in the model itself and in its input values, and to examine the relatively importance of these factors.

The IPCC guides (GPG 2000, IPCC 2006) use two main statistical concepts: the PDF and *confidence limits*. On Fig. 5 show PDF and cumulative distribution function (CDF) graphs. The PDF describes the range and relative likelihood of possible values; confidence limits give the range within which the underlying value of an uncertain quantity is thought to lie (confidence interval). The IPCC Guides suggest the use of a 95 % confidence interval, which is the interval that has a 95 % probability of containing the unknown true value.

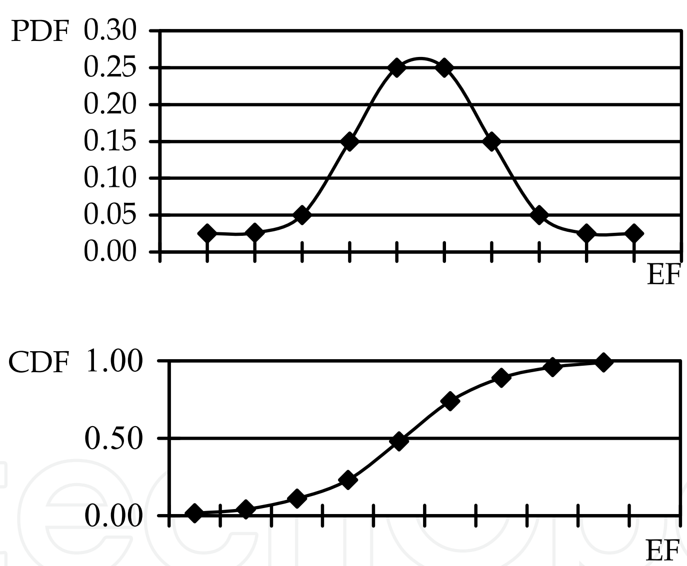

Fig. 5. PDF (a) and CDF (b) graphs

PDF is a mathematical function which characterizes the probability behaviour of population. It is a function $f(x)$ which specifies the relative likelihood of a continuous random variable X taking a value near x, and is defined as the probability that X takes a value between x and $x+dx$, divided by dx, where dx is an infinitesimally small number. Most PDFs require one or more parameters to specify them fully.

The probability that a continuous random variable X lies in between the values a and b is given by the interval of the PDF, $f(x)$, over the range between a and b:

$$\Pr(a \le x < b) = \int_{b}^{a} f(x)dx \ .$$

The PDF is the derivative (when it exists) of the distribution function ($F(x)$ for a random variable X specifies the probability $\Pr(X \le x)$ that X is less than or equal to x):

$$f(x) = \frac{dF(x)}{dx} \ .$$

In practical situations, the PDF used is chosen from a relatively small number of standard PDFs and the main statistical task is to estimate its parameters. Thus, for inventory applications, a knowledge of which PDF has been used is a necessary item in the documentation of an uncertainty assessment (GPG 2000).

Uncertainty information on the EF, AD and other parameters used for the uncertainty analysis must be collected to create PDF (for the Monte Carlo method) or mean and standard deviation of the data (for the error propagation method). As this uncertainty data is collected, the correlations between parameters should also be considered.

The measurement error is one of the first types of uncertainty of GHG emission inventories, which may be: results from errors in measuring, recording and transmitting information; finite instrument resolution; inexact values of measurement standards and reference materials; inexact values of constants and other parameters obtained from external sources and used in the data-reduction algorithm; approximations and assumptions incorporated in the measurement method and estimation procedure; and/or variations in repeated observations of the emission or uptake or associated quantity under apparently identical conditions. Measurement error can be reduced using more precise measurement methods, avoiding simplifying assumptions and ensuring, that measurement technologies are appropriately used and calibrated.

Uncertainties also may be a result of: measurements were attempted but no value was available (missing data); and measurement data are not available either because the process is not yet recognized or a measurement method does not yet exist (lack of completeness). Where a PDF can be identified, sources of uncertainty can be addressed by statistical means (*type A of uncertainty* for GUM 1993). There can be structural uncertainties that are not easily incorporated into a quantitative uncertainty analysis in the form of a PDF. These types of situations are typically outside the scope of statistics (*type B of uncertainty* for GUM 1993).

Comparison of uncertainty estimation in metrological and environmental guides are provided in Table 2 (Velychko O. & Gordiyenko T., 2005; Gordiyenko T. & Velychko O., 2006; Velychko O. & Gordiyenko T., 2007a; Velichko O. N. & Gordienko T. B., 2007c, 2009; Velychko O. M. & Gordiyenko T. B., 2008; Velychko O. & Gordiyenko T., 2009).

The pragmatic approach for producing quantitative uncertainty estimation is using the best available estimates, which are often a combination of measured data, published information, model outputs, and expert judgement. Although uncertainties determined from measured data are often perceived to be mote rigorous than uncertainty estimates based on models, and similarly.

Metrological guides	**Environmental guides**
Type A of GUM 1993 regulated using assessment of uncertainty (components evaluated by statistical methods to a series of repeated determinations) and use equation: $u_A = \frac{s}{\sqrt{n}}$, where: s is the standard deviation; n is the number of measurements.	Rule A of GPG 2000 regulated using assessment of uncertainty and use equation: $U_{total} = \frac{\sqrt{(U_1 \cdot x_1)^2 + (U_2 \cdot x_2)^2 + \ldots + (U_n \cdot x_n)^2}}{x_1 + x_2 + \ldots + x_n}$, where: U_{total} is percentage of uncertainty in the sum of the quantities*; x_i and U_i are the uncertain quantities and percentage of uncertainties associated with them, respectively.
Type B of GUM 1993 regulated using assessment of uncertainty (components evaluated by other means) and use equation: $u_B = \frac{U}{k}$, where: U is the expanded uncertainty given in Certificate; k is the coverage factor (typically $k = 2$).	Rule B of GPG 2000 regulated using assessment of uncertainty (if impossible use statistical processing) and use equation: $U_{total} = \sqrt{U_1^2 + U_2^2 + \ldots + U_n^2}$, where: U_{total} is percentage of uncertainty in the product of the quantities*; U_i are percentage of uncertainties associated with each of the quantities.
In GUM 1993 the overall uncertainty arising from the combination of type A and type B uncertainties calculated used equation: $u_c = \sqrt{\sum_{i=1}^{m} u_i^2}$ or $\hat{u}_c = \sqrt{\hat{u}_A^2 + \hat{u}_B^2}$, and $U_p = k \cdot u_c$ where: u_c is the total uncertainty; u_i is the components of uncertainty; U_p is the expanded uncertainty.	In IPCC 2006 the overall uncertainty arising from the combination of EF and AD uncertainty calculated used equation: $U_T = \pm\sqrt{(U_E^2 + U_A^2)}$, where: U_E is percentage of uncertainties associated with the EF; U_A is percentage of uncertainties associated with the AD, so long as $\lvert U_E \rvert$, $\lvert U_A \rvert$ < 60 %**.

* half the 95 % confidence interval divided by the total and expressed as a percentage;
** the 60 % limit is imposed because the rule suggested for U_T requires σ to be less than about 30 % of the central estimate, and we are interpreting the quoted range as ± 2σ.

Table 2. Uncertainty estimation in metrological and environmental guides

Probability distribution is a function giving the probability that a random variable takes any given value or belongs to a given set of values. The probability on the whole set of values of the random variable equals 1. Many commonly used PDF distributions of practical important are: uniform; triangular, normal; lognormal; and fractile (Fig. 6).

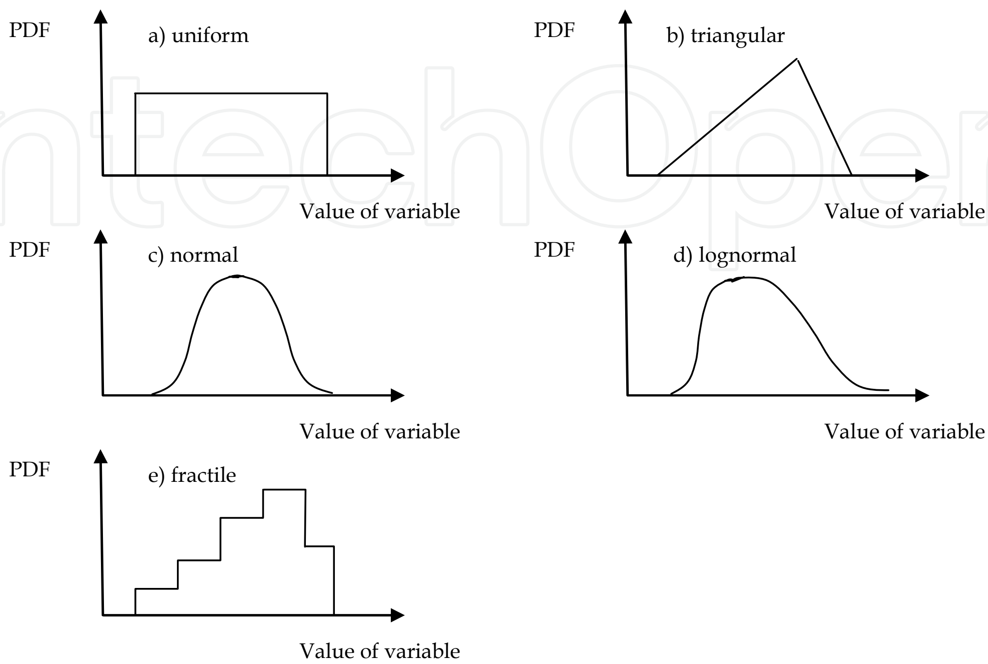

Fig. 6. Some commonly used PDF models

Uniform distribution describes an equal likelihood of obtaining any value within a range. Sometimes the uniform distribution is useful for representing physically-bounded quantities. The PDF of the uniform distribution is given by:

$$f(x) = \begin{cases} 1/(b-a), \text{ for } a \le x \le b, \\ 0 \quad \text{elsewhere,} \end{cases}$$

where:

$\mu = (a+b)/2$ is a mean and;

$\sigma^2 = (a+b)^2/12$ is the variance.

The *triangular distribution* is appropriate where upper and lower limits and a preferred value are provided by experts but there is no other information about the PDF. The triangular distribution can be asymmetrical. The PDF of the triangular distribution is given by:

$$f(x) = \begin{cases} 2(x-a)/\{(b-a)(m-a)\}, \text{ when } a \le x \le m \text{ and } a < m \le b, \\ 2(b-x)/\{(b-a)(b-m)\}, \text{ when } m \le x \le b \text{ and } a \le m < b, \\ 0 \quad \text{elsewhere,} \end{cases}$$

where:

a, b are minimum and maximum value respectively;

m is mode (most likely position), subject to $a \le m \le b$.

The *normal* (*or Gaussian*) *distribution* is most appropriate when the range of uncertainty is small, and symmetric relative to the mean. This distribution arises in situations where many individual inputs contribute to an overall uncertainty, and in which none of the individual uncertainties dominates the total uncertainty. The PDF of the normal distribution is given by:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}, \text{ for } -\infty \le x \le \infty.$$

The *lognormal distribution* may be appropriate when uncertainties are large for a non-negative variable and known to be positively skewed. If many uncertain variables are multiplied, the product asymptotically approaches lognormality. The PDF of the lognormal distribution is given by:

$$f(x) = \frac{1}{\sigma_l x\sqrt{2\pi}} e^{-\frac{(\ln x-\mu_l)^2}{2\sigma_l^2}}, \text{ for } 0 \le x \le \infty.$$

The parameters required to specify the function are: μ_l the mean of the natural log transform of the data; and σ_l^2 the variance of the natural log transform of the data. The data and information that the inventory compiler can use to determine the input parameters are: μ_l is mean; σ^2 variance; and the relationships:

$$\mu_l = \ln\frac{\mu^2}{\sqrt{\left(\sigma^2+\mu^2\right)}} \quad \text{and} \quad \sigma_l = \sqrt{\ln\left(\frac{\sigma^2}{\mu^2}+1\right)} \quad .$$

Fractile distribution is a type of empirical distribution in which judgements are made regarding the relative likelihood of different ranges of values for a variable (GPG 2000).

The rules for *uncertainties propagation* specify how to algebraically combine the quantitative measures of uncertainty associated with the input values to the mathematical formulae used in GHG national inventory compilation, so as to obtain corresponding measures of uncertainty for the output values. The *Monte Carlo analysis* is suitable for detailed category-by-category assessment of uncertainty, particularly where uncertainties are large, distribution is non-normal (non-Gaussian), the algorithms are complex functions and/or there are correlations between some of the activity sets, EF, or both (GPG 2000).

Simplified estimation of expanded measurement uncertainty for Type A is shown on Fig. 7.

Measurement uncertainty of the values equation is used:

$$Y = f(X_1, X_2, ..., X_m),$$

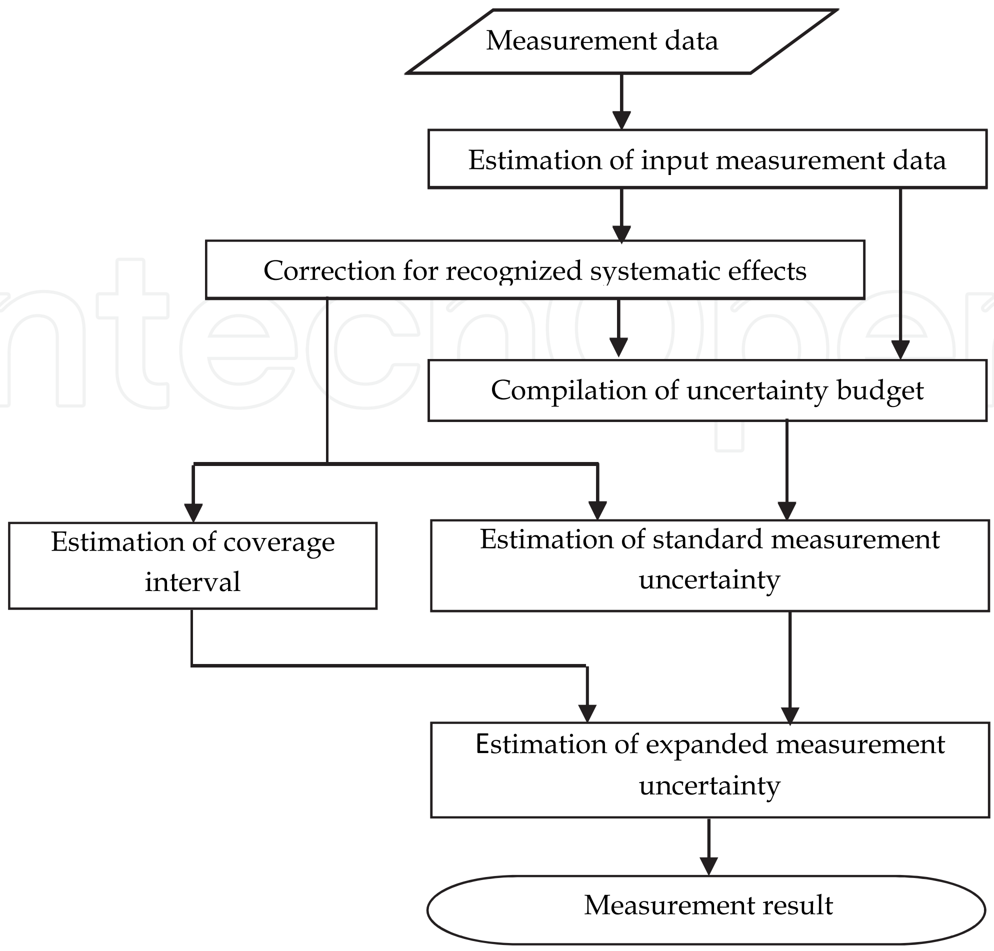

Fig. 7. Simplified estimation of expanded measurement uncertainty

where:

$X_1, \ldots, X_m$ are entrance value (direct measured value or other value which have an influence on measurement results);
m is quantity values;
f is functional dependence type.

Estimation of the standard measurement uncertainty $u_A(x_i)$ of measurement i-th input values without correlation input values may be calculated by means of the following equation:

$$u_A(x_i) = \sqrt{\frac{1}{n_i(n_i - 1)} \sum_{q=1}^{n_i} \left(x_{iq} - \overline{x}_i\right)^2} \ ,$$

where:

x_{iq} is the measurement results of i-th input values;

$\overline{x}_i = \frac{1}{n} \sum_{q=1}^{n_i} x_{iq}$ is the arithmetic median of measurement results of i-th input values.

The overall standard uncertainty u_c (Table 2) determined by a combination of uncertainties components; estimation of the expanded measurement uncertainty U_p may be calculated by means of the equation from Table 2 (GUM 1993).

Statistical uncertainty in the context of GHG inventories is usually presented by giving an uncertainty range expressed in a percentage of the expected mean value of the emission. This range can be determined by calculating the "confidence limits", within which the underlying value of an uncertain quantity is thought to lie for a specified probability. The "confidence level" determines the probability, that the true value of emission is situated within the identified uncertainty range.

Determining the *t*-factor *t* (standard error that is to be estimated follows a *t*-distribution) can be done by using the Table 3.

Number of measurements (*n*)	***t*-factor (*t*) for confidence level 95 %**
3	4,30
5	2,78
8	2,37
10	2,26
50	2,01
100	1,98
∞	1,96

Table 3. *t*-factors for the 95% confidence level

4. Uncertainty estimation with correlation values

Necessity in the analysis of covariance and autocorrelation for the uncertainty estimates of emission foul and greenhouse gases exists. It is importantly to investigate the correlations of the estimated values relevant to emissions as in the context one estimation and the various estimations of emission foul and GHG.

If correlation exists between input values then this correlation is essential and can not be ignored. Covariance of input values may be estimated experimentally, on condition of possible the change of input correlated values (the estimation of type A covariance), or with the using of necessary data on the correlation changeability of values which relate to this measurement (the evaluation of type B covariance).

In practical cases input values often appear to be correlated, as far as the evaluation of their values is used by the same standards, measuring instruments, standard data and even method of measurement which possess peculiar uncertainty. If direct measurement results are not correlated then calculated value of covariance is expected to be close to zero.

Covariance with the estimations of two input values may be equal to zero or selected as negligible, if: these values are not correlated (values measurement are run repeatedly in various independent experiments, or they present the various estimations of values which made independently); any values may be is accepted as an constant; there is negligible data for calculation of covariance related with the estimations of these values.

Comparison of the uncertainties estimations of input values with correlation in metrological and environmental guides are driven in Table 4 (Velychko O. & Gordiyenko T., 2007b).

Metrological guides	Environmental guides
Entrance value is non correlated	
Using estimation of uncertainty in accordance with the law of propagation of uncertainty and use equation (GUM 1993): $u_c(y)=\sqrt{\sum_{i=1}^{m}(\partial f/\partial x_i)^2}$, $u^2(x_i)=\sqrt{\sum_{i=1}^{m}u_i^2(y)}$ or $u_c(y)=\sqrt{c_1^2u^2(x_1)+c_2^2u^2(x_2)+...+c_m^2u^2(x_m)}$, where: $u(x_i)$, $u_i(y)$ are standard uncertainty input ($i=1,m$) and output value respectively; y, x_i are estimations of measurable value Y and input value X_i respectively.	Using estimation of uncertainty Rule A and use equation (GPG 2000, IPCC 2006): $U_{total}=\frac{\sqrt{(U_1\cdot x_1)^2+(U_2\cdot x_2)^2+...+(U_n\cdot x_n)^2}}{x_1+x_2+...+x_n}$, where: U_{total} is percentage of uncertainty in the sum of the quantities; x_i, U_i are uncertain quantities and percentage of uncertainties associated with them, respectively.
Entrance value is correlated	
Using estimation of uncertainty in accordance with the law of propagation of uncertainty and use equation (GUM 1993): $u_c(y)=\sqrt{\sum_{i=1}^{m}(\partial f/\partial x_i)u^2(x_i)+2\sum_{i=1}^{m-1}\sum_{j=i+1}^{m}u(x_i,x_j)}$ or $u_c(y)=\sqrt{\sum_{i=1}^{m}u_i^2(y)+2\sum_{i=1}^{m-1}\sum_{j=i+1}^{m}c_ic_ku(x_i,x_j)}$ where: $u(x_i,x_j)$ is estimation covariance with two input estimations x_i and x_j; y is estimation of measurable value Y; x_i, x_j are estimation input values X_i and X_j respectively.	Not numerical estimated in GPG 2000 and IPCC 2006.
The degree of correlation between x_i and x_j is characterized by the estimated correlation coefficient (GUM 1993): $r(x_i,x_j)=r(x_j,x_i)=u(x_i,x_j)/[u(x_i)u(x_j)]$, where: $r(x_i,x_j)=r(x_j,x_i)$; $-1\leq r(x_i,x_j)\leq 1$.	A value of correlation coefficient of +1 means that the variables have a perfect direct straight line relation; a value of –1 means that there is a perfect inverse straight line relation; and a value of 0 means that there is no straight line relation (GPG 2000). It is defined as the covariance of the two variables divided by the product of their standard deviations.

Table 4. Uncertainty estimation with correlation in metrological and environmental guides

For correlation coefficient $r(x_i, x_j)$ = ±1 uncertainties contribution is:

$$u_{i,j}(y) = \left|u_i(y) \pm u_j(y)\right| = \left|c_i u(x_i) \pm c_j u(x_j)\right| ;$$

if the estimates x_i and x_j are independent, $r(x_i, x_j)$ = 0, and a change in one does not imply an expected change in the other.

Uncertainties aggregation arises of two various processes: aggregation of emissions one gas which complies with the law of propagation of uncertainty; aggregation of emissions bound with several gases. Into second case emission must be result in common scale, and been used for this process consists in the application of Global Warming Potentials (GWP).

Comparison of the emission sources with allowance for correlation and covariance of input values in metrological and environmental guides are driven in Table 5.

Metrological guides	**Environmental guides**
Correlation and covariance for entrance value	
For correlation and covariance with type *A* using the following equation: $u(\bar{x}_i, \bar{x}_k) = \left[1/n(n{-}1)\right] \sum_{j=1}^{n} (x_{ij} - \bar{x}_i)(x_{kj} - \bar{x}_k)$.	The sample covariance of paired sample of random variables *X* and *Y* is calculated using the following equation (GPG 2000, IPCC 2006): $s_{xy}^2 = \frac{1}{n} \sum_{i}^{n} (x_i - \bar{x})(y_i - \bar{y})$, where: x_i, y_i, $i = 1,\ldots,n$ are items in the sample; $\bar{x}$ and $\bar{y}$ are sample means respectively.
For correlation and covariance with type *B* using the following equation: $u(x_i, x_k) = \sum_{l=1}^{L} c_{il} \cdot c_{kl} \cdot u^2(Q_l)$, where: c_{il} , c_{kl} are sensitivity coefficients respectively; $u(Q_l)$ is standard uncertainty of variables Q_l .	
Uncertainties contribution every input values and sensitivity coefficient	
Uncertainties contribution $u_i(y)$ every input values X_i to uncertainty $u(y)$ using the following equations (GUM 1993): $u_i(y) = \lvert c_i \rvert u(x_i)$; $c_i = \partial y/\partial x_i = \partial Y/\partial X_i \big\vert_{x_1, x_2, \ldots, x_m}$ where: c_i are sensitivity coefficients; y is estimation of measurable value *Y*; $x_1, \ldots, x_m$ are input values ($i = 1, m$). For direct measurement all sensitivity coefficients are equal 1.	Sensitivity coefficient λ calculated using the following equation (GPG 2000): $\lambda = \partial E_T / \partial a$, where: E_T is the aggregated emissions; a is input quantity (or parameter). Dispersion of tendency for emission two different time $E(t)$ and $E(t + \Delta t)$ with Δt using the following equation: $\sigma^2(\Delta E) = 2\sigma^2{}_E(1 - r(\Delta t))$. where: $r(\Delta t)$ is correlation coefficient

Table 5. Comparison of uncertainty contributions in metrological and environmental guides

Some variables which are necessary aggregation, do not are Gauss, large dispersion and correlated with other variables are have. In this case the application of Monte-Carlo method for uncertainties aggregation is presented the most preferable. The Monte Carlo analysis can be performed at the source category level, for aggregations of source categories, or for the inventory as a whole. It analysis can deal with PDF of any physically possible shape and width, can handle varying degrees of correlation (both in time and between source categories) and can deal with more complex models.

Algorithm of uncertainty estimation with correlation according to GUM 1993 is present on Fig. 8.

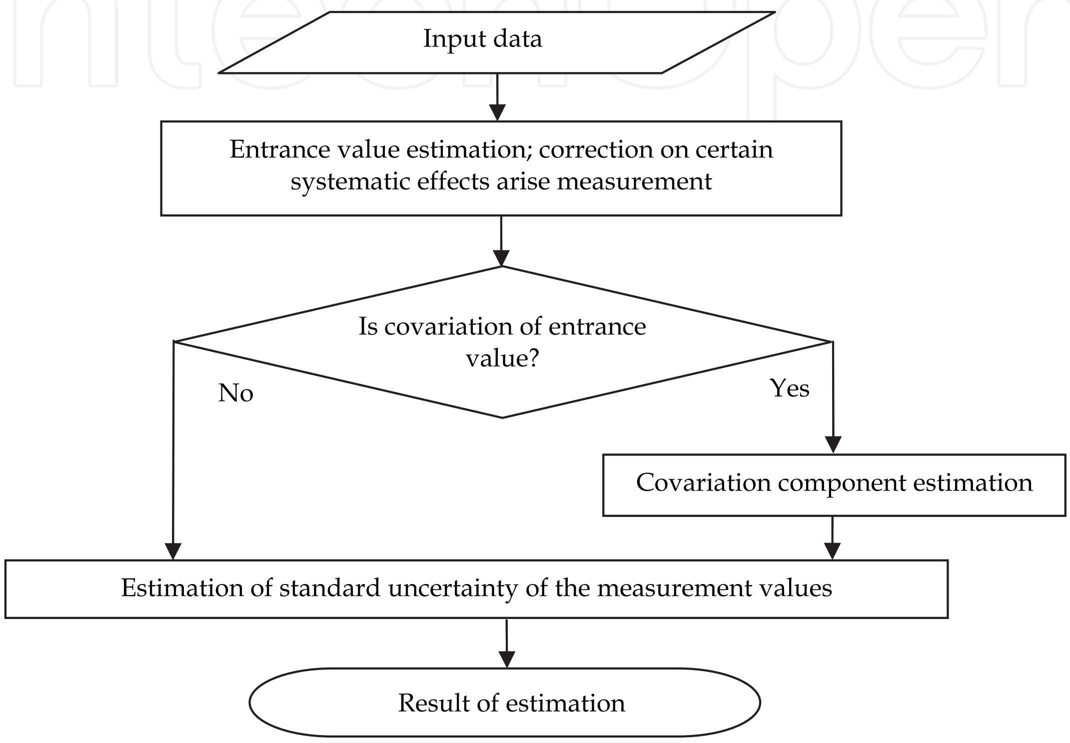

Fig. 8. Uncertainty estimation algorithm with correlation according to GUM 1993

Uncertainty results in compliance with GUM 1993 can be calculated with use a few well known commercially available software. Special software can be a useful tool for uncertainty estimation (Velychko O., 2008).

Overall uncertainty in total national GHG emissions in the current year, calculated using Rule A (corresponding Type A in accordance with GUM) and use equation

$$U_T = E_i \cdot U_{\sum B} / \sum E_T ,$$

where:

$U_{\sum B}$ is estimation of overall uncertainty Rule B;

E_i is GHG emissions from certain source category in CO_2-equivalent, Gg;

E_T is total GHG emissions from all source categories in CO_2-equivalent, Gg.

If overall uncertainty is correlated across years using estimation of overall uncertainty Rule B with uncertainty of EF only (assume AD to be equal 0 %).

For uncertainty of tendency of the GHG emission with EF uncertainty U_{EFt} (percentage) use equation:

$$U_{EFt} = c_A \cdot U_{EF} ,$$

where: c_A is Type A sensitivity coefficient.

If between EF have not correlation necessary use Type B sensitivity and to multiply by $\sqrt{2}$.

For uncertainty of tendency of the GHG emission with AD uncertainty U_{ADt} (percentage) use equation:

$$U_{ADt} = \sqrt{2} c_B \cdot U_{AD} ,$$

where: c_B is Type B sensitivity coefficient.

If between AD have correlation necessary use Type A sensitivity and not necessary to multiply by $\sqrt{2}$.

For estimation of uncertainty contribution U_{tdi} (percentage) which to make one's on tendency of overall GHG emission for each emission categories for Rule B use equation:

$$U_{tdi} = \sqrt{U_{EFt}^2 + U_{ADt}^2} .$$

For estimation of overall uncertainty contribution U_{td} (percentage) which to make one's on tendency of overall GHG emission use equation (GPG 2000):

$$U_{td} = \sqrt{\sum_i U^2_{tdi}} .$$

On Fig. 9 gives developed an uncertainty estimation algorithm with tendency, correlation and covariance according to GPG 2000 and IPCC 2006 which taking into consideration main requirements of GUM 1993.

5. Greenhouse Gas Protocol Uncertainty Tool

The IPCC 2006 for assessment GHG emissions used statistical AD of fuel combustion activities for different sectors and sources category and take account of direct and indirect GHG: CO_2, CH_4, N_2O, CO, NO_x, NMVOCs. Important element used IPCC 2006 is determination and/or selection EF which is take from IPCC 2006 ("default") or calculated as local for country, sectors, sources category or process. Accounts data submit in Common Reporting Format (CRF) which is standard data tables. IPCC 2006 contain chapter of key conceptions uncertainties, describe being types uncertainties, methods assessment (estimation) of uncertainties in GHG emission inventory.

The GHG Protocol Uncertainty Tool is based on the IPCC 2006 and should be considered as an addition to the calculation tools provided by the GHG Protocol Initiative. The GHG Protocol is to describe the functionality of the tool and to give user a better understanding of how to prepare, interpret, and utilize inventory uncertainty estimation (Velychko O. & Gordiyenko T., 2005, 2007a).

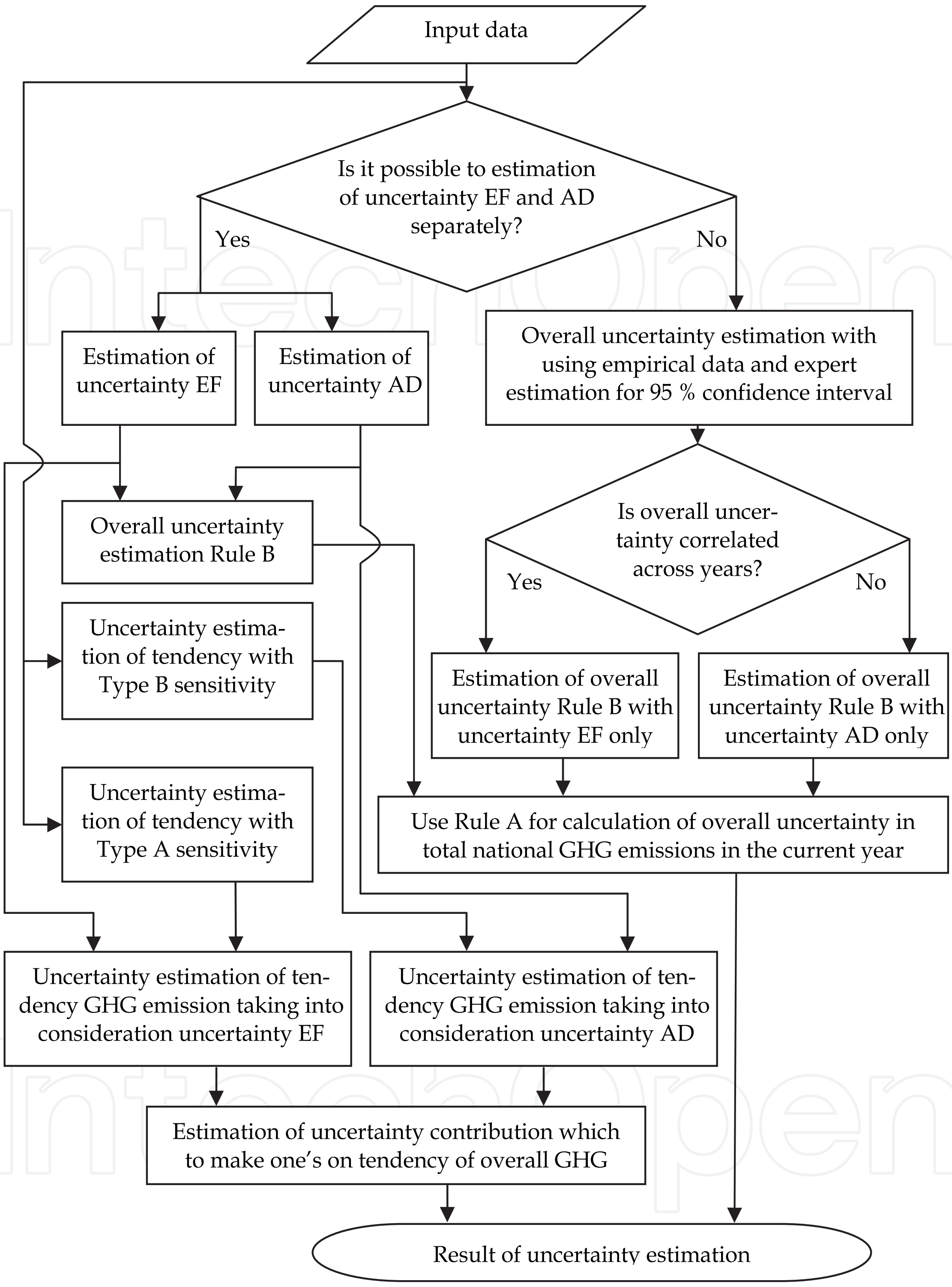

Fig. 9. Developed uncertainty estimation algorithm according to GPG 2000 and IPCC 2006

All IPCC guides use elements and reference to GUM 1993. GPG 2000 is the response to the request from the UNFCCC for the IPCC to complete its work on uncertainty and prepare a report on good practice in inventory management. Most of the statistical definitions given GPG 2000 lie within the context of "classical" frequency-based statistical inference, although it is acknowledged that this is not the only theory of statistical inference.

GPG 2000 describes two tiers of uncertainty estimation for GHG emission inventories for provided for combining source category uncertainties into uncertainty estimation for total national emissions and for emission trends: *Tier 1* – estimation of uncertainties by source category using the error propagation equation via Rules A and B and simple combination of uncertainties by source category to estimate overall uncertainty for one year and the uncertainty in the trend; *Tier 2* – estimation of uncertainties by source category using the Monte Carlo analysis, followed by the use of the Monte Carlo techniques to estimate overall uncertainty for one year and the uncertainty in the trend.

IPCC 2006 describes two tiers: *Tier 1* – for combining uncertainties in inventory data is to use the error propagation method. This method has limitations, in that it assumes normality in the input PDF (it cannot easily deal with correlations between datasets or across time and dependency between source categories that may occur because the same AD or EF may be used for multiple estimates); *Tier 2* – to use the Monte Carlo analysis which avoids all the limitations of the error propagation method (the principle of the Monte Carlo analysis is to select random values of each parameter, e.g., EF and AD, from within their individual PDF, and to calculate the corresponding values, e.g., emissions).

The GHG Protocol Uncertainty Tool is based on the IPCC 2006 and should be considered as an addition to the calculation tools provided by the GHG Protocol Initiative. The GHG Protocol Initiative has developed this guidance along with a calculation tool based on Excel spreadsheets. This calculation tool automates the aggregation steps involved in developing basic uncertainty estimation for GHG inventory data.

The GHG Protocol display uncertainties associated with GHG inventories: scientific uncertainty and uncertainty estimation last can be further classified into two types: model uncertainty and parameter uncertainty. *Scientific uncertainty* arises when the science of the actual emission and/or removal process is not sufficiently understood. *Uncertainty estimation* arises any time GHG emissions are quantified. Therefore all emission or removal estimates are associated with uncertainty estimation.

Model uncertainty refers to the uncertainty associated with the mathematical equations (i.e., models) used to characterize the relationships between various parameters and emission processes. Emission estimation models that consist of only AD times an EF only involve parameter uncertainties, assuming that emissions are perfectly linearly correlated with the AD parameter.

Parameter uncertainty refers to the uncertainty associated with quantifying the parameters used as inputs (e.g., AD and EF) into estimation models. This uncertainty can be evaluated through statistical analysis, measurement equipment precision determinations, and expert judgment. Emission estimated from direct emissions monitoring will generally involve only parameter uncertainty (e.g., equipment measurement error). The type of uncertainty most amenable to assessment of inventory is the uncertainties associated with parameters (e.g. AD, EF, and other parameters) used as inputs in an emission estimation model. GHG Protocol identified two types of parameter uncertainties in this context: *systematic* and *statistical* uncertainties (GHG Protocol).

Systematic uncertainty occurs if data are systematically biased (the average of the measured or estimated value is always less or greater than the true value). Biases can arise, because EF are constructed from non-representative samples, all relevant source activities or categories have not been identified, or incorrect or incomplete estimation methods or faulty measurement equipment have been used.

Statistical uncertainty results from natural variations (e.g. random human errors in the measurement process and fluctuations in measurement equipment). This uncertainty can be detected through repeated experiments or sampling of data. Complete and robust sample data will not always be available to assess the statistical uncertainty in every parameter. For most parameters only a single data point may be available. Random uncertainty can be detected through repeated experiments or sampling of data.

The different uncertainties associated with GHG inventories according GHG Protocol shown on Fig. 10.

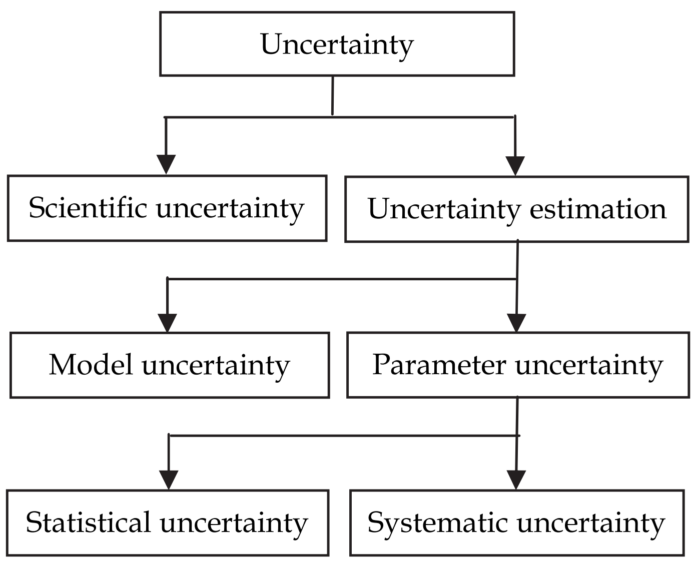

Fig. 10. Uncertainties associated with GHG inventories

The GHG Protocol is designed to aggregate statistical uncertainty assuming a *normal distribution* of the relevant variables and uses the first order error propagation method (Gaussian method), which corresponds to Tier 1 of the GPG 2000. This method should only be applied if the following assumptions are fulfilled: the errors in each parameter must be normally distributed (i.e. Gaussian); there must be no biases in the estimator function (i.e. that the estimated value is the mean value); the estimated parameters must be uncorrelated (i.e. all parameters are fully independent); individual uncertainties in each parameter must be less than 60 % of the mean. This procedure is repeated many times, using a computer, and the results of each calculation run build up the overall emission PDF.

A second approach is to use a technique based on a Monte Carlo simulation that allows uncertainties with any probability distribution, range, and correlation structure to be combined, provided they have been suitably quantified. This method, which corresponds to Tier 2 of the GPG 2000, can be used to estimate the uncertainty of single sources as well as to aggregate uncertainties for a site.

Calculation and ranking of uncertainties of indirectly measured emissions are shown in Table 6.

AD (e.g. quantity of fuel used)	Unit used to measure AD	Uncertainty of AD*, ± %	GHG EF	Unit of GHG EF (for kg CO_2)	Uncertainty of AD*, ± %	CO_2 emissions, kg	CO_2 emissions in metric tones	Uncertainty of calculated emissions, %	Certainty ranking	Auxiliary variable 1	Auxiliary variable 2
A	B	C	D	E	F	G	H	I	J	K	L
						A·D	G/1000	$I=\sqrt{C^2+F^2}$		(H·I)	K^2
1000.00	GJ	± 5.0	56.10	$kgCO_2$/ GJ	± 10.0	56100.00	56.10	± 11.2	Good	6.27	39.34
10.00	GJ	± 10.0	54.33	$kgCO_2$/ GJ	± 10.0	543.30	0.54	± 14.1	Good	0.08	0.01
…	…	…	…	…	…	…	…	…	…	…	…
* confidence interval expressed											

Table 6. The GHG Protocol Uncertainty Tool

Calculating aggregation of uncertainties uses equation:

$$\pm U = \pm \sqrt{\sum_{i=1}^{n} (H_i \cdot I_i)^2} \Big/ M ,$$

where:

H_i is CO_2 emissions from i-th source, tones;

I_i is percentage of uncertainty of calculated emissions from i-th source;

M is total CO_2 emissions, tones.

According GUM 1993 the symbol "±" should be avoided whenever possible because it has traditionally been used to indicate an interval corresponding with expanded uncertainty.

In GHG Protocol *measurement uncertainty* is usually presented as an uncertainty range, i.e. an interval expressed in ± percent of the mean value reported (e.g. 100 t ± 5 %). The likely causes of *uncertainty with direct measurement* are generally related to the measurement techniques used. Methods with a high degree of variability will typically lead to a high degree of statistical uncertainty in the final estimates. In the case of *indirect measurement* the uncertainties are related to the AD, and the EF.

The aggregation of uncertainties using this approach is facilitated by the GHG Protocol, which provides automated worksheets for directly and indirectly measured emissions.

For user that characterizes uncertainty numerically, a sum of squares approach may be used to calculate the confidence interval for the product of two or more factors. This approach is only valid if the uncertainties follow a normal distribution and if the individual uncertainties are less than 60%. The relative confidence interval (the ± percent) of the product is the square root of the sum of the squares of the relative (percent) confidence intervals of each factor.

6. The use of measurement units in environmental guides

SI units are recommended for use throughout science, technology and commerce. Each physical quantity has only one SI unit, even if this unit can be expressed in different forms. In some case the same SI unit can be used to express the values of several different quantities. The SI adopted series of prefixes for use in forming the decimal multiples and submultiples of SI units.

The International Committee of Weights and Measures (CIPM), recognizing that users would wish to employ the SI with units which are not part of it but are important and widely used, listed three categories of non-SI units: units to be maintained; to be tolerated temporarily; and to be avoided.

In reviewing this categorization the CIPM agreed a new classification of non-SI units: units accepted for use with the SI (for environmental guides – tonne or "metric ton"); units accepted for use with the SI whose values are obtained experimentally (-); and other units currently accepted for use with the SI to satisfy the needs of special interests (hectare). Non-SI unit tonne is accepted for use with the SI. It includes units, which are in continuous everyday use, in particular the traditional units of time and of angle, together with a few other units, which have assumed increasing technical importance (Tailor B. N., 1995).

The series of international standards on air quality includes the standardization of methods for the measurement of gases, vapours and particles (for example, ISO 4226). In order to enable results to be compared either between countries, it is essential to use agreed of measurement units to report the results and other relevant information. It is also desirable to keep the number of measurement units to a minimum. Those international standards lay down the units and symbols to be used when reporting results of air quality measurements.

Used in environmental guides and international standards (GPG 2000, IPCC 2006, ISO 4226) SI units, and also non-SI units and their conversion factors are shown in Table 7 (Velychko O. & Gordiyenko T., 2005; Velychko O. & Gordiyenko T., 2007a).

Units for quantity	**SI units**	**Non-SI units**	**Conversion factor**
Units for weight	Gram (g): Mg, Gg, Tg, Pg	Pound (lb)	1 lb = 454 g 1 g = 0.002205 lb 1 mg = 10^{-3} g 1 µg = 10^{-6} g 1 ng = 10^{-9} g 1 pg = 10^{-12} g 1 Mg = 10^{6} g 1 Gg = 10^{9} g 1 Tg = 10^{12} g 1 Pg = 10^{15} g
	Kilogram (kg)	Tonne (t): kt, Mt, Gt	1 t = 10^{3} kg = 1 Mg 1 kg = 2.2046 lb 1 kt = 10^{3} t = 1 Gg 1 Mt = 10^{6} t = 1 Tg 1 Gt = 10^{9} t = 1 Pg
		Short ton (sh t)	1 sh t = 0.9072 t 1 t = 1.1023 sh t
Units for length	Metre (m): µm	–	1 µm = 10^{-6} m
Units for substances*	Percent (% by volume)	–	–
	Percent (% by mass)	–	–
	Milligram per cubic metre (mg/m^3) Microgram per cubic metre (µg/m^3) Nanogram per cubic metre (ng/m^3) Picogram per cubic metre (pg/m^3)	Milligram per litre (mg/l)	1 mg/l = 10^{3} mg/m^3

Units for quantity	SI units	Non-SI units	Conversion factor
Units for energy	Joule (J): GJ, TJ	$Calorie_{IT}$ (cal_{IT})	1 cal_{IT} = 4.1868 J
		British thermal unit (Btu)	1 Btu = 1055.056 J 1 GJ = 10^9 J 1 Tj = 10^{12} J
		Tonne of oil equivalent (toe)	1 toe = $1{\cdot}10^{10}$ cal_{IT} = 41.868 GJ 1 ktoe = 41.868 TJ
		Kilowatt-hour (kWh)	1 kWh = $3{,}6{\cdot}10^6$ J 1 TJ = $2.78{\cdot}10^5$ kWh
Units for power	Watt (W): kW, MW, GW	Horse power (HP)	1 kW = 10^3 W 1 MW = 10^6 W 1 GW = 10^9 W 1 HP = 735.499 W
Units for square	Square metre (m^2)	Hectare (ha)	1 ha = 10^4 m^2
Units for volume	Cubic metre (m^3)	Dry gallon US (gal)	1 dm^3 = 10^{-3} m^3 1 gal dry(US) = 4.405 dm^3
Units for time	Second (s)	Minute (min)	1 min = 60 s
		Hour (h)	1 h = 60 min = 3600 s
		Day (d)	1 d = 24 h = 1440 min
		Year (yr)	–
Units for temperature	Kelvin (K)	Degree Celsius (°C)	1 °C = 1 K
Units for pressure	Pascal (Pa): kPa	Atmosphere (atm)	1 kPa = 10^3 Pa 1 atm = 101.325 kPa
* if concentrations are expressed in terms of mass per unit volume, temperature and pressure (as well as humidity) are required.			

Table 7. Used units for quantities and their conversion factors in environmental guides and international standards

7. Conclusion

Metrological and environmental international guides and standards comparison has shown peculiarities of used terms and uncertainty analysis with correlation and covariance of input values. Metrological and environmental guides use two types of uncertainty, and also used the Monte Carlo analysis of uncertainty. Environmental guides use more simplified approaches of the uncertainty analysis and also specifically use of data, which based on many models. Specific approaches to the uncertainty estimation in trend of GHG emissions imply realization of long-term observation and also environmental guide's consideration correlation of data across years.

It is necessary to apply international metrological guide to the expression of uncertainty in measurement – GUM 1993 and international vocabulary of metrology – VIM 2007, which are developed by eight international organizations in the field metrology, standardization, physicists and chemistry, during the preparation of environmental guides concerning the analysis of uncertainty. Also need to use approaches international metrological guide GUM 1993 for uncertainty assessment for GHG inventory with correlation or covariance of input values in the development of new and reconsideration of old international environmental guides is recommended.

SI units as well as traditional non-SI units are used in environmental guides. It considerably complicates the preparation of national experts of ecological information and its comparative analysis. Environmental guides that are used on international level must be prepared with preferably employment of SI units.

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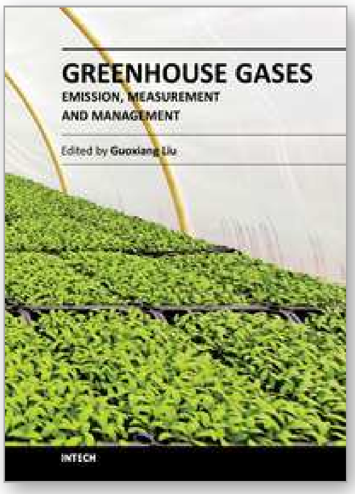

Greenhouse Gases - Emission, Measurement and Management
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Understanding greenhouse gas sources, emissions, measurements, and management is essential for capture, utilization, reduction, and storage of greenhouse gas, which plays a crucial role in issues such as global warming and climate change. Taking advantage of the authors' experience in greenhouse gases, this book discusses an overview of recently developed techniques, methods, and strategies: - A comprehensive source investigation of greenhouse gases that are emitted from hydrocarbon reservoirs, vehicle transportation, agricultural landscapes, farms, non-cattle confined buildings, and so on. - Recently developed detection and measurement techniques and methods such as photoacoustic spectroscopy, landfill-based carbon dioxide and methane measurement, and miniaturized mass spectrometer.

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