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Level and Trend Uncertainties of Kyoto Relevant Greenhouse Gases in Poland

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Contents

Abstract

The Kyoto Protocol is often described as a good first step towards reducing greenhouse gas (GHG) emissions into the atmosphere. The Protocol endorses emissions trading, joint implementation including “bubbling” between Annex I Parties, and a clean development mechanism that allows Annex I and non-Annex I Parties to act together to reduce emissions. However, the anticipated permit market will not function if uncertainties are not rigorously assessed and considered in any compliance process. With no reliable verification tool, it is impossible to effectively assess the different mechanisms and activities mentioned under the Protocol. Thus, it is very important to study the uncertainties underlying the Kyoto relevant GHGs, here with reference to Poland, because without the consideration of uncertainty robust verification can not occur.

This paper presents information about the data used in the calculations as well as the methods favored by the Intergovernmental Panel on Climate Change (IPCC). The so-called Tier 1 method of the IPCC for the evaluation of uncertainties is described in more detail.

This paper also provides a first quantitative overview on the Polish uncertainties of three Kyoto relevant GHGs, namely CO_2, CH_4, and N_2O, for 1988, 1990 and 1999. The main goals of the paper are to present the analytical calculations as well as additional calculations that are carried out to improve the evaluation of uncertainties. Recommendations are presented to reach these goals.

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About the Author

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Level and Trend Uncertainties of Kyoto Relevant Greenhouse Gases in Poland

Rafal Gawin

1 Introduction

The Kyoto Protocol is often described as a good first step towards reducing greenhouse gas (GHG) emissions into the atmosphere. The Protocol contains the first legally binding commitments to limit or reduce the emissions of six GHGs or groups of gases (i.e., CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6). For Annex I Parties, the targets agreed upon under the Protocol by the first commitment period (2008–2012) add up to a decrease in GHG emissions of 5.2% below 1990 levels in terms of CO_2 equivalents. Non-Annex I Parties are not required to take on specific commitments for emission reductions. The Kyoto Protocol also requires that any GHG accounting must be accurate, transparent, consistent, comparable to that of other countries, and verifiable. In addition, the Protocol endorses emissions trading (Article 17), joint fulfillment and implementation between Annex I Parties (Articles 4 and 6), and a clean development mechanism (CDM/Article 12) that allows Annex I and non-Annex I Parties to act together to reduce emissions (Bolin, 1998; Schlamadinger and Marland, 1998; Schneider, 1998; UNFCCC, 1998; WBGU, 1998; Jonas *et al*., 1999a).

Poland is a member of Annex I of the United Nations Framework Convention on Climate Change (UNFCCC) and Annex B of the Kyoto Protocol. Under its Protocol commitments, Poland is obligated to reduce its emissions by 6% compared to 1988, its base year.

The uncertainty evaluation of GHG emissions is of importance when, for example, the way a country meets its international obligations concerning emissions reduction is assessed, or the emissions trading mechanism is made operational, or finally, the risk of investment in options aimed at reducing GHG emissions is estimated (Szukalski, 2000). Thus, it is necessary to quantitatively analyze the uncertainties that underlie the emissions inventories in Annex I countries. Of course, it is very difficult to entirely eliminate the subjectivism of opinions and appraisals; thus, the author always has to deal with opinions and the problem of subjective choice.

Generally, the prime sources of errors in identifying national GHG emission levels in Poland are (Szukalski, 2000):

- The way categories of GHG sources and sinks are interpreted and defined, which is directly related to the national methodology in use for inventorying GHGs in Poland (e.g., IPCC, 1995, 1996; EMEP/CORINAIR, 2001);

- The accepted assumptions underlying the calculations;
- The existing system of collecting and filing statistical data (i.e. incomplete documentation), including the important *Official System of National Statistics* in Poland, presented by the Main Statistical Office (*GUS*) and the Energy Market Agency (*ARE*), which publishes data on the energy sector; and
- The inappropriate or inaccurate understanding of basic technological and economic processes, which determine the national emissions level and removal of GHGs.

The national inventories of GHG emissions, which have been made so far, have not been assessed quantitatively in terms of uncertainties. Practically, they only reveal a qualitative assessment. Such an assessment is shown in Table A-1 (see Appendix A), with an exemplary inventory made in 1999. The table shows the scope of the inventory and its qualitative evaluation on the basis of three indicators (H: high confidence in the estimation; M: medium confidence in the estimation; and L: Low confidence in the estimation). A general opinion on the entire inventory can be formed on the basis of this table, considering the objective of the inventory and the reliability of its results in qualitative terms. Unfortunately, we cannot learn what the uncertainty of the inventory is in quantitative terms.

This paper outlines the quantification of uncertainties and the approach applied in assessing the uncertainties underlying the emissions of Poland's GHGs (CO_2, CH_4, and N_2O) for 1988, 1990, and 1999. In addition, their Global Warming Potential (GWP) equivalents have been evaluated. The GWP factors express the total GHG emissions in CO_2 equivalent emissions using the following conversion factors (here: on a 100-year basis): 1 for CO_2, 21 for CH_4, and 310 for N_2O. This paper also evaluates the trend uncertainty between 1988 and 1999. The analyses do not include the emissions of HFCs, PFCs, and SF_6. Calculations were made for each of the inventories for 1988, 1990, and 1999, with relative uncertainties for activities and emissions factors introduced in the analytical calculations. Here, the activities are understood as the consumption of energy carriers, the manufacturing of products, the burning of biomass, the stock of animals, the production of useful minerals, the changes of arable and forest land, the volume of waste material and sewage, etc. Thus, the figures reflect human activities in the particular inventory categories. Hence, the uncertainty of emissions is understood as the error of emissions (here: two standard deviations — 95% confidence interval) relative to its expected value (for categories, subcategories, etc.). The uncertainties of emission factors and activity data were mostly obtained from Szukalski (2000) and additional calculations were made using other sources of information (e.g., IIASA and IPCC).

The first part of this paper presents information about the data used in the calculations as well as methods favored by the Intergovernmental Panel on Climate Change (IPCC). The so-called Tier 1 method of the IPCC for the evaluation of uncertainties is described in more detail.

The second part of this paper provides a first quantitative overview on the Polish uncertainties (i.e., level as well as trend uncertainties) of three Kyoto relevant GHGs, namely CO_2, CH_4 and N_2O.

The main goals of the paper are to present the analytical calculations as well as additional calculations that are carried out to improve the evaluation of uncertainties. Recommendations are presented to reach these goals.

2 Background

2.1 Sources of Information about Uncertainty Calculations

Scientists have been recognizing the importance of appropriate uncertainty estimates for emission inventories. Nevertheless, only a handful of studies exist, which actually approach uncertainties in inventories or their impact on the atmosphere (see Jonas and Nilsson, 2001 for an overview). Estimating uncertainty in national GHG inventories has become part of the IPCC's Good Practice Guidance (IPCC, 2000). To date, only a few countries have prepared such uncertainty estimates at differing levels of detail: the United Kingdom, Norway, the Netherlands, and Austria (Charles *et al.*, 1998; Rypdal and Zhang, 2000; van Amstel *et al.*, 2000; Jonas and Nilsson, 2001). Such a study was also done in Poland (Szukalski, 2000). However, only the uncertainty level for the 1998 inventory was estimated in quantitative terms.

2.2 Emission Evaluation in Poland

Emissions are estimated by the National Emission Centre in Poland. The data used to estimate activity data are mainly obtained from the Main Statistical Office (*GUS*) and the Energy Market Agency (*ARE*). Emission factors were provided by Polish experts, obtained from the literature, or based on expert judgments.

Emission data from source (j) and pollutant (i) are usually estimated according to:

$$Emission_{ij} = Activity\_Data_{ij} * Emission\_Factor_{ij} . \qquad (2\text{-}1)$$

In a few cases, the equation is more complicated (e.g., emissions from road traffic). However, in the Polish case, all emissions have been estimated on the basis of equation (2-1). To these ends, activity data within each subsector must be distinguished (e.g., fuel types in energy, manufactured products in industry, the kinds of animals in agriculture, etc.).

The total emissions of pollutant (i) is the sum of the emissions from each source (j):

$$Emission_i = \sum_j (Activity\_Data_{ij} * Emission\_Factor_{ij}). \qquad (2\text{-}2)$$

The emissions have been estimated separately for six GHGs, namely CO_2, CH_4, N_2O, NO_x, CO, NMVOC for 1988 and 1990 [following the IPCC Draft Guidelines (IPCC, 1994)] and CO_2, CH_4, N_2O, HFC, PFC, and SF_6 for 1999 [following the IPCC Revised Guidelines (IPCC, 1996)].

The total GHG emissions estimate is the sum of all the pollutants (i) weighted by their GWP:

$$Total\_Emission = \sum_i (GWP_i * Emission_i). \qquad (2\text{-}3)$$

All input data (both activity data and emission factors) are uncertain.

2.3 Simplifications of the Parameter Format

In order to become acquainted with the statistically independent sectors and activity data, some assumptions and aggregations had to be done. The following simplifications were made:

- All emissions were aggregated to the national level;
- The sectors and sources were combined into the IPCC Standard (relating to 1988 and 1990 data) and the IPCC Revised (relating to 1999 data) source/sink sectors. This implies that some emission factors had to be averaged;
- Some adjustments and splits of source/sink categories were adopted in order to make the IPCC Standard (IPCC, 1995) and the IPCC Revised (IPCC, 1996) reporting formats comparable;[1]
- The energy carriers have been grouped into the main types: furnace oil, diesel oil, liquid natural gas, petrol, aviation fuel, other petroleum products, high methane natural gas, natural nitrited gas, coking coal, brown coal, coke, artificial gases, biomass, and other (not included elsewhere);
- The manufactured products in industry were grouped into the main types: iron production, cement production, lime production, nitrid acid production, ammonia production, soda ash production, other production, food and drink production. (The activity data from drink production were recalculated from hectoliter units into teragram units using the assumption that 1 liter = 1000 grams.);
- The subsectors: 5A: Changes in Forest and Other Biomass Stocks as well as 5C: Abandonment of Managed Lands, both from the Land Use Change and Forestry sector, were grouped into one subsector;[2] and
- The subsectors: 5B: Forest and Grasslands Conversion as well as 5D: CO_2 Emissions and Removals from Soil, both from the Land Use Change and Forestry sector, were grouped into one subsector.[3]

2.4 Emissions in 1988 and 1990

The official 1998 and 1990 emission estimates are the emission figures provided by the Polish Foundation for Energy Efficiency (PFEE) in 1997. The GHG emissions in Poland have been reported according to the IPCC (1994) Draft source/sink categories [excluding summary tables, which have been reported according to the IPCC (1995)

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[1] With respect to the two IPCC reporting formats, there are only differences within the main categories and the methodology of estimating emissions has improved.
[2] The subsectors: 5A and 5C relate to the IPCC Revised (IPCC, 1996) source/sink categories structure.
[3] The subsectors: 5B and 5D relate to the IPCC Revised (IPCC, 1996) source/sink categories structure.

Standard source/sink categories]. The emissions of the following GHGs have been reported: CO_2, CH_4, N_2O, NO_x, CO, and NMVOC. With respect to the emissions in 1988, the first estimate was done in 1991 and the results were reported according to the categories structure of the OECD (1991). The second estimate for 1988 was done in 1996 and the results were presented according to the categories structure of the IPCC (1994) Draft Guidelines. Tables B-1 and B-2 show Poland's 1988 and 1990 emission estimates for CO_2, CH_4, and N_2O (see Appendix B).

2.5 Emissions in 1999

The emission estimates for 1999 are the official emission figures provided in 2001 by the National Emission Centre in Poland. Poland's emissions have been reported according to the IPCC (1996) Revised source/sink and GHG categories. This means that GHGs such as CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6 are reported. The estimates of emissions were done using "top-down" methods [e.g., the Reference Approach (IPCC, 1996) in the Fuel Combustion sector]. In some cases, "simple methods" were used due to the lack of statistical data. Poland's 1999 emission estimates for CO_2, CH_4, and N_2O are shown in Table B-3 (see Appendix B).

3 Determination of Uncertainties in Input Parameters

3.1 Introduction

Uncertainties in inventory data have different explanations. Processes generating emissions may be variable in time and space and consequently it is difficult to establish the appropriate scheme of emission estimation and define a representative emission factor. The representative emission factors (or activity data) may be inaccurate, lacking, and substituted by assumptions — or emissions may not have been estimated at all. Furthermore, inventories may contain errors originating from data processing or basic data.

In general, the uncertainties of emission inventory data cannot be directly derived from observations. For each input data the variance, probability distribution, and possible dependencies should be assessed. There is good knowledge of this in only a few cases. However, for most data there is an assessment of the uncertainties of input databases on indirect sources (published data), while in some cases it is based on expert judgments.

As the data set is the sum of a lot of data with associated assumptions, the weak or wrong assumptions for parts of the data set will frequently not be very crucial. On the other hand, it has been suggested that the human mind may be biased towards systematically assessing too high or too low values. According to Morgan and Henrion (1990), the human mind has a tendency to underestimate the importance of systematic errors, so in general it could be assumed that weakly founded assessments might underestimate the uncertainties of the data set.

Two kinds of calculations were made in the presented research:

- 1st calculations: the uncertainty ranges of activity data and emission factors used in these calculations were mostly obtained from Szukalski (2000) and are included in the tables in Appendix C (column "1st calculations"); this is a first quantitative overview;
- 2nd calculations: the uncertainty ranges of activity data and emission factors used in these calculations were obtained from Szukalski (2000) as well as from other sources of information (e.g., IIASA and IPCC) or based on assumptions and are included in the tables in Appendix C (column "2nd calculations"); this is an improvement of uncertainty evaluation in Poland.

3.2 Means

The true values of activity data and emission factors are unknown. The parameters on which the estimations are based are frequently called a "best estimate". The "best estimates" are determined in the emission inventory development work and are based on Polish measurements, literature data, or statistical surveys. Some data are based on expert judgements (see Section 2.2).

A point for discussion is whether these "best estimates" represent the mean, the median, or something else. In this paper, it is assumed that the "best estimate" equals the mean because of the assumption that all parameters (activity data and emission factors) are normally distributed. Otherwise, how "probable" the mean value is depends on the particular distribution in each case.

3.3 Uncertainties and the Probability Distributions of Activity Data

A probability distribution is the description of the probabilities of all possible values in a sample space (Cullen and Frey, 1999). This may be represented mathematically as a probability distribution — a probability density function. In addition to its mean value, the standard deviation is the next important property of this function. Further parameters may be needed in order to describe non-normal probability density functions (Cullen and Frey, 1999; Morgan and Henrion, 1990).

The activity data are frequently statistical data based on sample surveys or censuses. The standard deviation or probability density of survey data are usually not available. However, the uncertainty of statistical data may also have contributions from errors in the population/sampling, processing errors, etc., which are not the properties of the data set itself.

Important activity data are those relating to the use of energy. Total energy consumption is determined from sale statistics or consumer surveys. Total energy use may also be determined for commercial fuels from the equation: *Total_Use = Production + Import + Stock Changes – Export*. These two data sets are independent and the spread in data gives an indication of statistical error. Generally, the total energy use is less uncertain than the energy use in each sector. For some sectors (e.g., the energy and manufacturing industries) the energy use is well known, while in the household and service sectors it is more uncertain. In the analysis, the author has only distinguished between the different uncertainties of different energy carriers, taking into consideration all of sector 1A: Fuel Combustion [relating to the IPCC (1996) Revised source/sink structure]. Furthermore, the errors in the various energy carriers may be correlated, however, the author has ignored this when the different energy carriers in this analysis have been aggregated into main fuel types. The above-mentioned assumption was also applied by Jonas and Nilsson to their simplified procedure of uncertainty calculation in the ENERGY module of their Austrian Carbon Database (ACDb) Study (Jonas and Nilsson, 2001). They concluded that the uncertainty calculations of both the simplified procedure and the more advanced (Monte Carlo) technique, described in Section 4 of this paper, agree if compared on the basis of uncertainty classes introduced by them (see Jonas and Nilsson, 2001: Section 4.2.5 for an overview).

Table C-1 in Appendix C presents the relative uncertainty ranges of activity data used in the analytical calculations (i.e., 1st and 2nd calculations). This table also contains information about the sources of where the data were obtained.

Appendix C only shows the uncertainty ranges of activity data for 1988 because the same uncertainties are used for the calculations of the other years (i.e., 1990 and 1999). All activity data used in the calculations are assumed to be normally distributed and uncertainty ranges are understood as two standard deviations (95% confidence interval).

The high values of uncertainties of activity data have been assigned to the following subsectors (see Table C-1 in Appendix C; 1st calculations):

- 1A: Fuel Combustion — relating to the fuels used in transport (i.e., diesel oil, petrol and aviation fuel), fuels used in the energy and transformation industries subsectors (i.e., other petroleum products), fuels used in the industries subsector (i.e., other natural gases, included only in the 1990 emission inventory), residential use of gases (i.e., liquid natural gas), and combustion of biomass;
- 4: Agriculture — relating to the on-site burning of agricultural residues subsector;
- 5: Land Use Change and Forestry — relating to the changes in forest and other biomass stocks as well as abandonment of managed lands subsectors; and
- 6: Waste.

Concerning the 2nd calculations, the following assumptions were made:

- opposite to the 1st calculations, which treated coking coal as a power coal (used for heat and power plants), the author assumed a greater uncertainty of 2% for this activity data; and
- opposite to the 1st calculations, which treated the uncertainties of the following activity data: iron production, nitrid acid production, ammonia production, soda ash production, other production, food and drink production (all from sector 2: Industrial Processes), the author assumed a greater uncertainty for this activity data, i.e., the same as for lime production (2%).

All uncertainties of activities taken from Szukalski (2000) were accepted on the basis of official statistical data issued by the Central Statistical Office in Poland (*GUS*) as well as the analysis of emission inventories (i.e., for 1988, 1990, 1991–1998) and the opinions of experts. The uncertainty ranges of activity data used in the calculations (both 1st and 2nd calculations) are also in accordance with the quality assessment of emissions included in Table A-1 in Appendix A.

3.4 Uncertainties and the Probability Distributions of Emission Factors

The ideal emission factor is derived from a set of measurements, where there are no systematic errors in the measurements, and under the assumption that the derived emission factor represents the "real world". In this case, the standard deviation and probability density of the emission factor may be directly derived from the data on which it is based. However, this ideal emission factor does not exist. All of the emission factors, reported by the National Emission Centre in Poland, are provided by Polish experts as well as special studies, or obtained from the literature, or are experts' judgements.

Tables C-2 to C-4 in Appendix C present the relative uncertainties of the emission factors (CO_2, CH_4, and N_2O) that were used in the analytical calculations (i.e., 1st and 2nd calculations). Information about the sources of the obtained data is also included.

Appendix C only shows the uncertainties of the emission factors for 1988 because the same uncertainties are also used for the calculations of the other years (i.e., 1990 and 1999). All emission factors used in the calculations are assumed to be normally distributed and the uncertainty is understood as two standard deviations (95% confidence interval).

Sectors that have been assigned small values of uncertainty are:

- 1A: Fuel Combustion — relating to CO_2 emission factors (all fuel categories) and N_2O emission factors (furnace oil, diesel oil, natural gas);
- 2: Industrial Processes — relating to CO_2 emission factors (all activity categories excluding iron production); and
- 4: Agriculture — relating to N_2O emission factors of the agricultural soils subsector.

The uncertainty of the CH_4 emission factor relating to ammonia production and other production from sector 2 has been assumed to be 10% concerning the quality assessment of CH_4 emissions from this subsector (see Table A-1 in Appendix A), i.e., "medium confidence in the estimation".

Concerning the 2nd calculations, the following assumptions were made:

- opposite to the 1st calculations, which treated the uncertainties of CO_2 emission factors of the following activities: lime production, ammonia production, soda ash production, other production, food and drink production (all from sector 2: Industrial Processes) as the values obtained from Jonas and Nilsson (2001), the author assumed a smaller uncertainty for those emission factors, i.e., the same as for cement production (4%); and

- opposite to the 1st calculations, which treated the uncertainty of the N_2O emission factor for the agricultural soils subsector (sector 4: Agriculture) as 8%, the author assumed this emission factor to be 40%; the quality assessment of N_2O emissions from the above-mentioned subsector is: “high confidence in the estimation” (see Table A-1 in Appendix A); however, concerning the uncertainty ranges of this emission factor evaluated by, e.g., the UK (509%), Austria (501%) or recommended by the IPCC (2 orders of magnitude), the value of 40% is more likely to be appropriate.

All uncertainties of emission factors obtained from Szukalski (2000) were accepted on the basis of the analysis of emission inventories (i.e., 1988, 1990, 1991–1998) as well as data from professional literature and experts’ opinions. The uncertainty ranges of emission factors used in the calculations (both 1st and 2nd calculations) are also in accordance with the quality assessment of emissions included in Table A-1 in Appendix A.

3.5 Dependencies Between Activity Data

The activity data in Equation 2-2 (see Section 2.2) are, in principle, independent. However, the same activity data may be used to estimate more than one emission source (e.g., in the agriculture sector). In addition, the same activity data may be used to estimate more than one pollutant (especially in the case of energy emissions).

More specifically, the cases when activity data might be dependent are:

- The consumption of oil products in each sector;
- The consumption of gasoline and diesel (oil products) for the applications: (i) cars with catalytic converter, (ii) cars without catalytic converter, and (iii) off-road;
- The number of domestic animals. The same data are used in the estimations of (i) methane from enteric fermentation, (ii) methane from manure management, and partly (iii) nitrous oxide from agricultural soils; and
- Where the same activity data are used to estimate the emissions of more than one pollutant.

In this work, the activity data are assumed to be independent because they are aggregated into the main IPCC (1996) source/sink categories.

3.6 Dependencies Between Emission Factors

The case of dependencies between emission factors is difficult to handle correctly. In a perfect data set the different emission factors from independent estimates would have been used for all the emission sources.

In this work, the emission source/sink categories are aggregated into the main IPCC (1996) source/sink categories. This implies that most of the emission factors are averaged (some of them are obtained directly from the Polish report on emissions elaborated by the National Emission Centre) or estimated using the equation: *Emission_Factor = Emission / Activity_Data*. All emission factors used for estimating total (or level) uncertainty are different,[4] which is why they have been assumed to be independent.

3.7 Dependencies Between Data in Base Year (1988) and End Year (1999)

The assumptions made about dependencies between the two years (1988 and 1999) are extremely important for the main conclusions of this analysis concerning the trend uncertainty from 1988 to 1999. The estimates made for the two years will largely be based on the same data and assumptions.

Activity data

The activity data are determined independently in the two years and are, in principle, not dependent. Correlation could be considered only in the cases where activity data cannot be updated annually or where the updates are based on the extrapolations or interpolations of data for another year. However, in these calculations this is not the case.

This implies that errors in activity data are assumed to be random; hence systematic method errors are insignificant. However, it is likely that the activity data are still correlated, as they have been determined using the same methods.

Emission factors

It has been assumed that most of the emission factors are unchanged from the base year (1988) to the end year (1999). Those that are not are all based on the same assumption. This implies that the emission factors are fully correlated between the two years.

In fact, special studies were made in 2001 in Poland in order to improve the 1999 emission inventory, which treated the following sectors/subsectors:

- 1A3: Transport;
- 1B1: Fugitive Emissions from Coal Production;
- 4A: Enteric Fermentation;
- 4B: Manure Management;
- 4D: Field Burning of Agricultural Residues;
- 5: Land Use Change and Forestry; and
- 6A: Solid Waste.

This implies that some of the emission factors relating to the above-mentioned sectors/subsectors were changed. However, the quality assessment of emission estimates for 1999 (NEC, 2001) is the same as for 1998 (Szukalski, 2000). Consequently the author assumed that no great changes have been introduced and that the emission factors stay fully correlated.

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[4] They have different values and/or carry different physical units.

4 Data Processing

4.1 Uncertainty Concepts Being Discussed

The term “level uncertainty” should be understood as the uncertainty of the level of emissions, while the term “trend uncertainty” should be understood as the uncertainty of the trend of emissions. The trend of emissions is the difference between the levels of emissions in the two years considered.

This paper only discusses the level and trend uncertainty concepts. These two concepts are specifically mentioned by the IPCC. The level and trend uncertainty concepts are a discrete view, which means that only two points in time are considered. With reference to the Kyoto Protocol, clear and ambiguous situations exist. For instance, under the Protocol a situation is considered clear if the reduced emissions fall (i) outside the level uncertainty, or (ii) within the trend uncertainty. By way of contrast, a situation appears ambiguous when the reduced emissions fall within the level but outside the trend uncertainty. Figure 1 presents the discussed situations in view of the Kyoto Protocol.

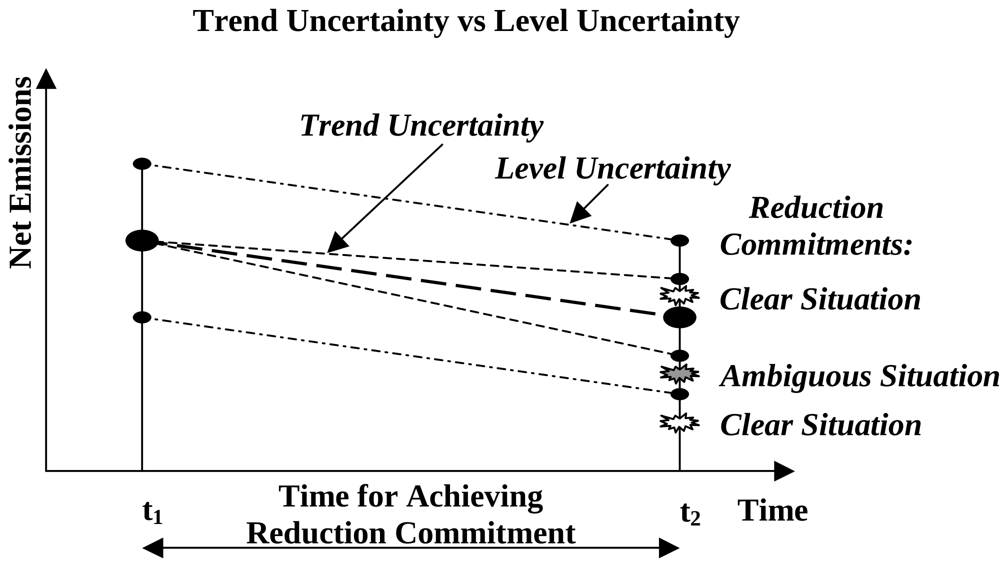

Figure 1: Level and trend uncertainty concepts. Source: Jonas *et al*. (2000), modified.

There is also a new concept, which is dynamically based. This concept attempts to grasp the issues of verification and links the dynamics of carbon emissions with the dynamics of their underlying uncertainties. This work is still underway (Jonas *et al.*, 1999b, 2000; Gusti and Jęda, 2002; Dachuk, 2002).

The Kyoto Protocol is not clear on which uncertainty concept (level or trend) should be used. However, the dynamical concept (also called Verification Time Concept) is believed to be superior to the two-point-in-time IPCC uncertainty concept (Jonas and Nilsson, 2001).

4.2 Favored Methods: Tier 1 and Tier 2

There are many methods that can be used for the propagation of uncertainties including those under the general descriptions of analytical methods, approximation methods, and numerical methods. Once the uncertainties in the source categories have been determined, they may be combined to provide the uncertainty estimates for the entire inventory in any year and the uncertainty in the overall inventory trend over time.

For the purpose of propagating uncertainties in national GHG inventories, two general methods are specifically mentioned by the IPCC (2000):

- Tier 1 method: The estimation of uncertainties by source category using the error propagation equation and the simple combination of uncertainties by the source category to estimate the overall uncertainty for one year and the uncertainty in the trend; and
- Tier 2 method: The estimation of uncertainties by the source category using the Monte Carlo analysis, followed by using Monte Carlo techniques to estimate the overall uncertainty for one year and the uncertainty in the trend.

The error propagation equation yields two convenient rules for combining the uncorrelated uncertainties under addition and multiplication (IPCC, 2000):

- Rule A: Where uncertain quantities are to be combined by addition, the standard deviation of the sum will be the square root of the sum of the squares of the standard deviations of the quantities that are added with the standard deviations all expressed in absolute terms (this rule is exact for uncorrelated variables).

  Using this interpretation, a simple equation can be derived for the uncertainty of the sum that, when expressed in percentage terms, becomes:

$$U_{total} = \frac{\sqrt{(U_1 \cdot x_1)^2 + (U_2 \cdot x_2)^2 + \ldots + (U_n \cdot x_n)^2}}{x_1 + x_2 + \ldots + x_n} \qquad (4\text{-}1)$$

  where U_{total} is the percentage uncertainty in the sum of quantities (half the 95% confidence interval divided by the total, i.e., mean, and expressed as a percentage); x_i and U_i are the uncertain quantities and the percentage uncertainties associated with them, respectively.

- Rule B: Where uncertain quantities are to be combined by multiplication, the same rule applies except that the standard deviation must be expressed as the fraction of appropriate mean values (this rule is approximate for all random variables).

  A simple equation can also be derived for the uncertainty of the product, expressed in percentage terms:

$$U_{total} = \sqrt{U_1^{\ 2} + U_2^{\ 2} + \ldots + U_n^{\ 2}} \qquad (4\text{-}2)$$

where U_{total} is the percentage uncertainty in the product of quantities (half the 95% confidence interval divided by the total and expressed as a percentage); U_i are the percentage uncertainties associated with each of the quantities.

The conditions imposed for using this method are:[5]

- The uncertainties are relatively small, the standard deviation divided by the mean value being less than 0.3;
- The uncertainties are not correlated; and
- The uncertainties have Gaussian (normal) distributions.

Under these conditions, the uncertainty calculated for the emission rate is appropriate. The method can be extended to allow for covariances.

The law of error propagation is the method of combining variances and covariances for the variety of functions, including those used in inventories, that is based on the Taylor expansion. Most emission inventories are the sums of emissions that are the products of activity data and emission factors. Assuming that both quantities have some uncertainty, such inventory equations are non-linear with respect to the uncertainty calculations. Therefore, the law of error propagation equation provides only an approximate estimate of the combined uncertainty. Systematic error caused by neglecting this non-linearity in inventories can be assessed case-by-case. Both Tier 1 and Tier 2 methods are very inaccurate with respect to functions containing inverse, higher power or exponential terms (Cullen and Frey, 1999). Terms can be included to allow for the effects of covariance. Once the covariance occurs, the use of the Monte Carlo approach is preferable (see also Jonas and Nilsson, 2001).

Numerical statistical techniques, particularly the Monte Carlo techniques, are suitable for estimating uncertainty in emissions (due to uncertainties in activity data and emission factors) when:

- Uncertainties are large;
- The algorithms are complex functions;
- Correlations occur between some of the activity data sets, emission factors, or both; and
- Their distribution is non-Gaussian.

Uncertainties in emission factors or activity data or both are often large and may not have normal distributions. In these cases, it may be difficult or impossible to combine uncertainties using conventional statistical rules. The Monte Carlo analysis can deal with this situation. The principle is to perform the inventory calculation many times by means of a computer, each time with the uncertain emission factors or model parameters and activity data chosen randomly (by the computer) within the distribution of uncertainties specified initially by the user. This process generates an uncertainty distribution for the inventory estimate that is consistent with the input uncertainty

[5] In fact, only the first and second conditions are necessary for the method to be applicable (IPCC, 2000).

distributions on the emission factors, model parameters, and activity data. The method is very data and computing time intensive, but is well suited to the problem of propagating and aggregating uncertainties in an extensive system such as a national GHG inventory. A more detailed description and applications of this method are in Annex 3 and the Glossary of Good Practice Guidance (IPCC, 2000) as well as Cullen and Frey (1999).

4.3 Tier 1 Method

The Tier 1 analysis is used in this paper. Some important reasons for using the Tier 1 method are:

- It is spreadsheet based and therefore easy to apply;
- It is valid if emissions are estimated using the equation "activity data times emission factor" (this is exactly the case for the Polish emissions inventory);
- It uses uncertainties for activity data and emission factors with the assumption that their probabilities are normally distributed;
- It is useful for a first-order overview on level and trend uncertainties;
- It supports "top-down" thinking; and
- Easily accessible to external verification.

Tier 1 analysis estimates uncertainties by using the law of error propagation in two steps. First, Rule B approximation (described in Section 4.2) is used to combine the uncertainties of emission factors and activity data by source category and GHG. Second, Rule A approximation (also described in Section 4.2) is used to derive the overall level uncertainty in national emissions and their trend uncertainty between the base year and the current year.

The Tier 1 approach should be implemented using Table 1. The table has to be completed using uncertainties for activity data and emission factors by source category. Different gases should be entered separately as CO_2 equivalents (i.e., the emissions should be multiplied by their 100-year GWP values). The trend uncertainties are estimated using two sensitivities:

- Type A sensitivity: the change in the difference in overall emissions between the base year and the current year, expressed as a percentage, resulting from 1% increase in the emissions of a given source category and gas in both the base year and the current year; and
- Type B sensitivity: the change in the difference in overall emissions between the base year and the current year, expressed in percentage, resulting from 1% increase in the emissions of a given source category and gas in the year under discussion (typically: current year) only.

Conceptually, Type A sensitivity arises from the uncertainties that equally affect emissions in the base year and the current year and Type B sensitivity arises from the uncertainties that only affect emissions in the current year. The uncertainties that are fully correlated between the years will be associated with Type A sensitivities and the uncertainties that are not correlated between the years will be associated with Type B sensitivities. Usually, the emission factor uncertainties will tend to have Type A sensitivities and the activity data uncertainties will tend to have Type B sensitivities. However, this association will not always hold and it is possible to apply Type A sensitivities to activity data and Type B sensitivities to emission factors to reflect the particular national circumstances. Both sensitivities are simplifications introduced for analyzing correlation.

Table 1: Tier 1: Uncertainty calculation. Source: IPCC (2000).

A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**
IPCC Source Category	Gas	Base year emissions	Year t emissions	Acti-vity data uncert.	Emis-sion factor uncert.	Com-bined uncert.	Combined uncert. as % of total national emissions in year t	Type A sensi-tivity	Type B sensi-tivity	Uncert. in trend national emissions introduced by emission factor uncert.	Uncert. in trend in national emissions introduced by activity data uncert.	Uncert. intro-duced into the trend in total national emissions
		Gg CO_2 equivalent	Gg CO_2 equivalent	%	%	%	%	%	%	%	%	%
e.g., 1.A1. Energy Industries Fuel 1	CO_2											
e.g., 1.A1. Energy Industries Fuel 2	CO_2											
etc.	…											
Total												

Once the uncertainties, introduced into the national emissions by Type A and Type B sensitivities, have been calculated they can be assessed using the law of error propagation (Rule A) to give the overall uncertainty in the trend.

The columns in Table 1 are labeled A to M and contain the following information (IPCC, 2000):

- A and B show the IPCC source category and GHG.
- C and D are the inventory estimates in the base year and the current year,[6] respectively, for the source category and gas specified in columns A and B, expressed in CO_2 equivalents.
- E and F contain the uncertainties for the activity data and emission factors respectively, derived from a mixture of empirical data and expert judgment, entered as half of the 95% confidence interval divided by the mean and expressed as a percentage.

[6] The current year is the most recent year for which inventory data are available.

- G is the combined uncertainty by source category derived from the data in columns E and F using the error propagation equation (Rule B). The entry in column G is therefore the square root of the sum of the squares of the entries in columns E and F.
- H shows the uncertainty in column G as the percentage of total national emissions in the current year. This is a measure of the degree of uncertainty introduced into the national emissions total by the source category in question. The entry in each row of column H is the entry in column G multiplied by the entry in column D, divided by the total at the foot of column D. The total at the foot of column H is an estimate of the percentage uncertainty in total national emissions in the current year, calculated from the entries above using Rule A. This total is obtained by adding the squares of all the entries in column H and taking the square root.
- I shows how the percentage difference in emissions between the base year and the current year changes in response to a 1% increase in source category emissions in both the base year and the current year. This shows the sensitivity of the trend in emissions to a systematic uncertainty in the emissions estimate (i.e., one that is correlated between the base year and the current year). This is Type A sensitivity as defined above.
- J shows how the percentage difference in emissions between the base year and the current year changes in response to a 1% increase in source category emissions in the current year only. This shows the sensitivity of the trend in emissions to random error in the emissions estimate (i.e., one that is not correlated between the base year and the current year). This is Type B sensitivity as described above.
- K uses the information in columns I and F to show the uncertainty introduced into the trend in emissions by emission factor uncertainty, under the assumption that uncertainty in emission factors is correlated between years. If the emission factor uncertainties are not correlated between years then the entry in column J should be used in place of that in column I and the result multiplied by $\sqrt{2}$.
- L uses the information in columns J and E to show the uncertainty introduced into the trend in emissions by activity data uncertainty, under the assumption that uncertainty in activity data is not correlated between years. If the activity data uncertainties are correlated between years then the entry in column I should be used in place of that in column J and the $\sqrt{2}$ factor does not then apply.
- M is the estimate of uncertainty introduced into the trend in national emissions by the source category in question. Under the Tier 1 method, this is derived from the data in columns K and L using Rule B. The entry in column M is therefore the square root of the sum of the squares of entries in columns K and L. The total at the foot of this column is an estimate of the total uncertainty in the trend, calculated from the entries above using the error propagation equation. This total is obtained by adding the squares of all the entries in column M and taking the square root.

4.4 Sequence of Analytical Analysis

The sequence of analytical analysis concerning the identification of the uncertainties of GHG emissions may be presented as follows:

1. Collecting statistical data on activities in accordance with the categories and subcategories defined in compliance with the methodology of the IPCC. This data covers the period of time when the national GHG emission inventories were made.
2. Collecting data on the results of GHG emission inventories, which have been already made and, in particular, the activity data and emission factors of individual GHGs, in accordance with the categories and subcategories of emissions (on the basis of IPCC methodology).
3. Identifying uncertainties (95% confidence level) on the basis of the statistical analyses of empirical data collected for the individual activities (e.g., energy carriers, mineral raw materials, the stock of animals, arable area, etc.).
4. Analyzing and validating the results obtained.
5. Correcting input data and repeating the analysis. The procedure is to be repeated until the correct results are obtained (in accordance with critical evaluation by independent experts).

5 Analysis

5.1 Uncertainties in Emission Levels

Level uncertainty calculations were made for 1988, 1990, and 1999. Tables 2–4 show the results of the calculations, i.e.:

- 1st calculations: the uncertainties of activity data and emission factors used in these calculations were mostly obtained from Szukalski (2000) and are included in the tables in Appendix C (column “1st calculations”); this is a first quantitative overview;
- 2nd calculations: the uncertainties of activity data and emission factors used in these calculations were obtained from Szukalski (2000) as well as from other sources of information (e.g., IIASA and IPCC) or based on assumptions and are included in the tables in Appendix C (column “2nd calculations”); this is considered to be an improvement of the uncertainty evaluation.

Table 2: Level uncertainties for 1988. GHGs considered: CO_2, CH_4, and N_2O.

Source Categories for 1988	Level Uncertainty[a]					
	1st calculations			2nd calculations		
	CO_2 [%]	CH_4 [%]	N_2O [%]	CO_2 [%]	CH_4 [%]	N_2O [%]
1A: Fuel Combustion	3	15	16	3	15	16
1B: Fugitive Emissions from Fuels	13	25	-	13	25	-
2: Industrial Processes	3	11	70	3	11	70
4: Agriculture	-	40	13	-	40	41
5: Land Use Change and Forestry	32	60	60	32	60	60
6: Waste	-	67	-	-	67	-
Level Uncertainty of Total Emission (CO_2, CH_4, and N_2O)		**5**			**5**	

[a] The uncertainty of the activity data as well as emission factors (CO_2, CH_4, and N_2O) are listed in the Tables in Appendix C.

Table 3: Level uncertainties for 1990. GHGs considered: CO_2, CH_4, and N_2O.

Source Categories for 1990	Level Uncertainty[a]					
	1st calculations			2nd calculations		
	CO_2 [%]	CH_4 [%]	N_2O [%]	CO_2 [%]	CH_4 [%]	N_2O [%]
1A: Fuel Combustion	3	15	16	3	15	16
1B: Fugitive Emissions from Fuels	13	24	-	13	24	-
2: Industrial Processes	3	11	70	3	11	70
4: Agriculture	-	40	13	-	40	41
5: Land Use Change and Forestry	32	60	60	32	60	60
6: Waste	-	66	-	-	66	-
Level Uncertainty of Total Emission (CO_2, CH_4, and N_2O)		**6**			**6**	

[a] The uncertainty of the activity data as well as emission factors (CO_2, CH_4, and N_2O) are listed in the Tables in Appendix C.

Table 4: Level uncertainties for 1999. GHGs considered: CO_2, CH_4, and N_2O.

Source Categories for 1999	**Level Uncertainty[a]**					
	1st calculations			**2nd calculations**		
	CO_2 [%]	**CH_4 [%]**	**N_2O [%]**	**CO_2 [%]**	**CH_4 [%]**	**N_2O [%]**
1A. Fuel Combustion	3	43	16	3	43	16
1B. Fugitive Emissions from Fuels	13	23	-	13	23	-
2. Industrial Processes	3	11	70	3	11	70
4. Agriculture	-	40	13	-	40	41
5. Land Use Change and Forestry	29	60	60	29	60	60
6. Waste	-	70	-	-	70	-
Level Uncertainty of Total Emission (CO_2, CH_4, and N_2O)		**6**			**6**	

[a] The uncertainty of the activity data as well as emission factors (CO_2, CH_4, and N_2O) are listed in the Tables in Appendix C.

Two kinds of calculations were made. Concerning the 2nd calculations, all assumptions have been described in Sections 3.3 and 3.4. However, the most important changes, which influence the overall uncertainty most, relate to sector 4 (the uncertainty of the N_2O emission factor of agricultural soils) and to sector 1A (the uncertainty of the CO_2 emission factor of coking coal).

The degrees of decrease (increase) of emissions in 1999 in Poland relating to 1988 are:

- CO_2 emissions: 35.2% decrease (including removals);
- CH_4 emissions: 28.4% decrease; and
- N_2O emissions: 6.6% increase.

The shares of particular emissions in 1988 and 1999 in Poland relating to overall emissions (calculated as CO_2 equivalents) are:

- CO_2 emissions: 83.4% (1988) and 80.2% (1999), including removals;
- CH_4 emissions: 12.5 % (1988) and 13.3% (1999); and
- N_2O emissions: 4.1% (1988) and 6.5% (1999).

It should also be mentioned that the CO_2 emissions from sector 1A amount to 96.7% of the overall CO_2 emissions in Poland in 1988 (96.3% in 1999 respectively).

This implies that:

- CO_2 emissions from sector 1A greatly influence the overall uncertainty in spite of the fact that the uncertainty, which has been assigned to this sector, is quite low; and
- The overall uncertainty slightly increased from 1988 to 1999 because of the slight decrease of the emissions from sector 1A. Therefore, the larger uncertainties from the other sectors have a slightly greater influence on the overall uncertainty.

The other sectors also influencing the overall uncertainty are:

- 4: Agriculture — with respect to the N_2O emissions (only the 2nd calculations);
- 5: Land Use Change and Forestry — with respect to the CO_2 emissions; and
- 6: Waste — with respect to the CH_4 emissions.

The uncertainty of Poland's total emissions in the range 4.5% to 6% (for the years 1988, 1990, and 1999) seems to be low. Concerning the relative uncertainty classes introduced by and described in Jonas and Nilsson (2001), Poland's overall emissions can be assessed as falling into Class 2 (5–10%) (excluding 1988 level uncertainties).[7] This uncertainty (or relative uncertainty class) is determined by the uncertainty of the CO_2 emissions from sector 1 – Energy, which belong to Class 1 (0–5%), which can be considered typical for many countries (Jonas and Nilsson, 2001). The uncertainties with respect to CH_4 and N_2O are responsible for Poland's overall classification under Class 2. Concerning Austria's uncertainty evaluation, the greater uncertainties related to CH_4 and N_2O emissions (in comparison with Poland) result in classifying Austria "in total" under Class 3 (10–20%) (see Jonas and Nilsson, 2001).

5.2 Uncertainties in Emission Trend

Trend uncertainty calculations were made between 1988 and 1999. Table 5 presents the results of the calculations.

Table 5: Trend uncertainty for 1988 and 1999. GHGs considered: CO_2, CH_4, and N_2O.

Source Categories	**Trend Uncertainty[a]**					
	1st calculations			**2nd calculations**		
	CO_2 [%]	**CH_4 [%]**	**N_2O [%]**	**CO_2 [%]**	**CH_4 [%]**	**N_2O [%]**
1A: Fuel Combustion	1.7	0.1	0	1.8	0.1	0
1B: Fugitive Emissions from Fuels	0	0.1	-	0	0.1	-
2: Industrial Processes	0	0	0	0	0	0
4: Agriculture	-	0.3	0.5	-	0.3	0.8
5: Land Use Change and Forestry	2.5	0	0	2.5	0	0
6: Waste	-	2.2	-	-	2.2	-
Trend Uncertainty of Total Emission (CO_2, CH_4, and N_2O)		**3.8**			**3.9**	

[a] The uncertainty of the activity data as well as emission factors (CO_2, CH_4, and N_2O) are listed in the Tables in Appendix C.

Two kinds of calculations were also made. The trend uncertainty calculations were carried out in consideration of the same assumptions concerning the uncertainties of

[7] The author treated only three GHGs, namely CO_2, CH_4, and N_2O. It is likely that if all GHGs (CO_2, CH_4, N_2, NO_x, CO, and NMVOC), for the 1988 inventory are taken into account, the overall uncertainty is closer to or even greater than 5%.

activity data and emission factors that were previously accepted for the level uncertainty calculations. Therefore, the main conclusions of the obtained results are the same as in the case of the level uncertainty calculations.

Concerning the dependencies of parameters between the two years considered (i.e., 1988 and 1999), it was assumed that the activity data are not correlated and the emission factors are fully correlated. This greatly influenced the results of the calculations. As a consequence, calculations were also made with the assumption that the emission factors are independent (i.e., not correlated) between the two years considered in order to show how different the results are in the calculations. The total trend uncertainties obtained in this case are: **5.7%** (1st calculations) and **13.7%** (2nd calculations).

6 Conclusions and Recommendations

In the case of level and trend uncertainty calculations, the author followed the Tier 1 method recommended by the IPCC. This method is an analytical approach, which gives a first-order overview on level and trend uncertainties and which is easily accessible to external verification.

Generally speaking, the level uncertainties as well as trend uncertainties calculated in the 1st calculations, using the uncertainties of activity data and emission factors included in the tables in Appendix C (column "1st calculations"), appear to be low. However, bearing in mind that the author treated only three GHGs (i.e., CO_2, CH_4, and N_2O), the evaluated value of overall uncertainty is not outside "reasonable limits". It should also be mentioned that all uncertainties of activity data and emission factors used in the calculations are in accordance with the quality assessment of emissions evaluation included in Table A-1 in Appendix A. Concerning the relative uncertainty classes introduced by and described in Jonas and Nilsson (2001), Poland's overall emissions should fall into Class 2 (5–10%). This uncertainty (or relative uncertainty class) is determined by the uncertainty of the CO_2 emissions from sector 1 – Energy, which belong to Class 1 (0–5%), which can be considered typical for many countries (Jonas and Nilsson, 2001). The uncertainties with respect to CH_4 and N_2O are responsible for Poland's overall classification under Class 2. Concerning Austria's uncertainty evaluation, the greater uncertainties related to CH_4 and N_2O emissions (in comparison with Poland) result in classifying Austria "in total" under Class 3 (10–20%) (see Jonas and Nilsson, 2001).

Second calculations were also made. In this case, the author did not change the values of uncertainties of activity data and emission factors, which seem to be reliable and are in accordance with the quality assessment of the emissions evaluation included in Table A-1 in Appendix A. The author only changed those, which are quite different from the uncertainty ranges evaluated for other countries (e.g., Austria, the UK, Norway) or appear to be too high or too low (especially the N_2O emission factor from subsector 4D: agricultural soils). However, the accepted changes in uncertainties are still in accordance with the above-mentioned quality assessment included in Table A-1 in Appendix A. The results obtained in the 2nd calculations do not differ to a large degree from the results obtained in the 1st calculations.

Under the Kyoto Commitments, Poland must reduce GHG emissions by 6% below the 1988 emission level. The present situation is as follows: Poland has reduced its GHG emissions in 1999 by about 33% relative to 1988 (in 1998 by about 29%, which means that Poland's emissions reveal a decreasing tendency). Therefore, it seems that Poland does not have a problem in achieving its reduction commitments.

However, there is the following question: What will happen under an emissions trading situation? If Poland wants to trade emissions in the future, it is necessary to know whether Poland's emission estimates are certain. The Kyoto Protocol is not "a gentleman's agreement" and thus uncertainty estimation needs to be done.

As mentioned in Section 3, all uncertainties of activity data relating to sector 1A: Fuel Combustion were provided by Polish experts on the basis of the statistical yearbooks of the Main Statistical Office in Poland (*GUS*) and the Energy Market Agency (*ARE*). In addition, the uncertainties of emission factors from the above-mentioned sector are provided by Polish experts on the basis of the analysis of GHG inventories made for the years 1988–1998. As mentioned in Section 5.1, the emissions (especially CO_2 emissions) from sector 1A have a great influence on the overall uncertainty. Therefore, the author concluded that the uncertainty evaluated for this sector (about 3%) seems to be low. However, it does not mean that the calculated value of uncertainty is not valid. All uncertainties of activity data, which have been assigned to the other sectors are experts' judgments or are obtained from the literature. The uncertainties of emission factors were provided by Polish experts on the basis of the analysis of inventories of GHG inventories made for the years 1988–1998. In 2001, special studies were made for some sectors in order to improve the emission estimates for the 1999 inventory (see Section 3.7). Therefore, detailed special studies should be undertaken for Poland with reference to uncertainties of activity data and emission factors because the experts' judgments or the literature might not be trustworthy sources of information.

In order to be a good partner in negotiations relating to possible emissions trading in the near future, Poland should provide uncertainty calculations. Moreover, it is very important to provide the uncertainty calculation covering all GHGs as well as full carbon accounting (FCA) in estimating the emissions. Without uncertainty calculations, covering all GHGs and FCA, Poland may not obtain all of the possible profits resulting from emissions trading and other mechanisms mentioned by the Kyoto Protocol. It is also very important to provide emission forecasts until 2010, the Kyoto commitment year.

In order to reach all of the above-mentioned goals, it is important to organize some workshops with experts not only from Poland but also from other countries. Of special importance is the collaborative work between IIASA, Polish (e.g., the National Emission Centre, the System Research Institute of the Polish Academy of Sciences, etc.) and other institutes. The discussions, workshops, and collaboration would help to find the best way of reaching all these goals.

This paper only illustrates the first-order overview on the uncertainty of Kyoto relevant GHGs in Poland. The author concludes that Polish experts' judgments and some assumptions relating to the uncertainty ranges of activity data and emission factors may be not valid. The value of total uncertainty equaling 5% or 6% is low. However, the uncertainty calculations made in this research covered only CO_2, CH_4, and N_2O emissions. If Poland wants to negotiate possible emissions trading and participate in other mechanisms mentioned by the Kyoto Protocol, it is crucial to undertake special studies focusing on uncertainties and provide uncertainty calculations covering all GHGs and FCA.

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Appendix A

Table A-1: Overview of Poland's GHG inventory for 1999. Source: NEC (2001).

GHG Source and Sink Categories	CO_2		CH_4		N_2O		Document-ation[a,c]	Disaggreg-ation[d]
	Estimate[a]	Quality[b]	Estimate[a]	Quality[b]	Estimate[a]	Quality[b]		
Total National Emissions and Removals	ALL	H/M	ALL	M	ALL	M/L	H/M	3
1. Energy	ALL	H/M	ALL	M	ALL	M/L	H/M	3
1.A: Fuel Combustion Activities Sectoral Approach	ALL	H	ALL	M/L	ALL	M/L	H/M	3
1A1: Energy Industries	ALL	H	ALL	M	ALL	L	H/M	3
1A2: Manufacturing Industry & Construction	ALL	H	ALL	M	ALL	M	H/M	3
1A3: Transport	ALL	M	ALL	L	ALL	L	H/M	3
1A4: Other Sectors	ALL	H	ALL	M	ALL	M	H/M	3
1A5: Other	PART	H	PART	M	PART	M	H/M	3
1B: Fugitive Emissions from Fuels	ALL	M	ALL	M	NO		M	3
1B1: Solid Fuels	NO		ALL	M	NO		M	3
1B2: Oil and Natural Gas	ALL	M	ALL	M	NO		M	3
2. Industrial Processes	ALL	M	ALL	M	ALL	M	M	3
2A: Mineral Products	ALL	M	NO		NO		M	3
2B: Chemical Industry	ALL	M	ALL	M	ALL	M	M	3
2C: Metal Production	ALL	M	ALL	M	ALL	M	M	3
2D: Other Production	ALL	M	ALL	M	ALL	M	M	3
2E: Production of HFCs, PFCs, SF_6	NO		NO		NO		NO	
2F: Consumption of HFCs, PFCs, SF_6	NO		NO		NO		M	3
2G: Other	NE		NE		NE			
3. Solvent and Other Product Use	NO		NO		NO			
4. Agriculture	NA		ALL	M	ALL	H/M	M	3
4A: Enteric Fermentation	NA		ALL	M	NA		M	3
4B: Manure Management	NA		PART	M	NE		M	3
4C: Rice Cultivation								
4D: Agricultural Soils	NA		NA		ALL	H	H	3
4E: Prescribed Burning of Savannas								
4F: Field Burning of Agricultural Residues	NA		ALL	M	ALL	M	M	3
4G: Other								
5. Land-Use Change and Forestry	ALL	M	ALL	M	ALL	M	M	3
5A: Changing in Forest and Other Biomass Stocks	ALL	M	NA		NA		M	3
5B: Forest and Grassland Conversion	ALL	M	ALL	M	ALL	M	M	3
5C: Abandonment of Managed Lands	ALL	M	NO		NO		M/L	3
5D: CO_2 Emissions & Removals from Soil	PART	M	NO		NO		M	2
5E: Other								
6. Waste	NE		ALL	M	NE		M	3
6A: Solid Waste Disposal on Land	NA		PART	M	NA		M	2
6B: Wastewater Handling	NO		ALL	M	NE		M	3
6C: Waste Incineration	NE		NE		NE			
6D: Other								
7. Other								
Memo Items:								
International Bunkers	ALL	M	ALL	L	ALL	L	M	3
Aviation	ALL	M	ALL	L	ALL	L	M	3
Marine	ALL	M	ALL	L	ALL	L	M	3
CO_2 Emissions from Biomass	ALL	L					L	3

[a] PART: Partly estimated; ALL: Full estimate of all possible sources; NE: Not estimated; IE: Estimated but included elsewhere; NO: Not occurring; NA: Not applicable.
[b] H: High confidence in the estimation; M: Medium confidence in the estimation; L: Low confidence in the estimation.
[c] H: High (all background information included); M: Medium (some background information included); L: Low (only emission estimates included).
[d] 1: Total emissions estimated; 2: Sectoral split; 3: Subsectoral split.

Appendix B

Table B-1: Poland's emission estimates for 1988. Source: PFEE (1997a).

IPCC Specification	**Fuel**	**Emission [Gg]** CO_2	CH_4	N_2O
Fuel Combustion Activities	Furnace Oil	13980	0.167	0.293
	Diesel Oil	19863	1.621	1.139
	Liquid Natural Gas (LNG)	379	0.009	0.001
	Petrol	10070	6.028	0.278
	Aviation Fuel	820	0.038	0.048
	Other Petroleum Products	1429	0.067	0.006
	High Methane Natural Gas	18339	16.683	0.033
	Natural Nitrited Gas	2615	0.273	0.005
	Coking Coal	266954	4.589	3.955
	Brown Coal	65520	0.404	0.828
	Coke	36694	0.621	0.445
	Artificial Gases	26178	8.278	0.021
	Biomass	0	7.585	0.135
	Other	164	0.004	0.002
	Totals	*463003*	*46.368*	*7.189*
Fugitive Emissions from Fuels	Coal Production	-	1043.348	-
	System of Crude Oil and Gas	53	204.863	-
	Totals	*53*	*1248.211*	-
Industrial Processes	Iron Production	738	4.101	-
	Cement Production	8492	-	-
	Lime Production	3546	-	-
	Nitrid Acid Production	-	-	7.436
	Ammonia Production	3	11.456	11.690
	Soda Ash Production	24	-	-
	Other	0	0.450	0.971
	Food and Drink	771	-	-
	Totals	*13574*	*16.007*	*20.097*
Agriculture	Enteric Fermentation	-	805.833	-
	Manure Management	-	56.180	-
	Agricultural Soils	-	-	43.090
	Field Burning of Agr. Residues	-	1.477	0.076
	Totals	-	*863.490*	*43.166*
Land Use Change and Forestry	Changes in Forest and Other Biomass Stocks Abandonment of Managed Lands	-35705	-	-
	Forest and Grasslands Conversion CO_2 Emissions and Removals from Soils	959	0.500	0.003
	Totals	*-34746*	*0.5*	*0.003*
Waste	Solid Waste	-	835.055	-
	Industrial Waste Water	-	121.503	-
	Municipal Waste Water	-	9.093	-
	Totals	-	*965.651*	-
National Totals		***441884***	***3140.228***	***70.455***
GRAND TOTAL			**529670**	

Table B-2: Poland's emission estimates for 1990. Source: PFEE (1997b).

IPCC Specification	**Fuel**	**Emission [Gg]**		
		CO_2	**CH_4**	**N_2O**
Fuel Combustion Activities	Furnace Oil	11163	0.486	0.237
	Diesel Oil	15.758	1.331	0.922
	Liquid Natural Gas (LNG)	98	0.002	0
	Petrol	10340	5.872	0.308
	Aviation Fuel	887	0.026	0.056
	Other Petroleum Products	2185	0.076	0.006
	High Methane Natural Gas	16891	14.182	0.030
	Natural Nitrited Gas	2002	0.118	0.004
	Other Natural Gases	874	0.269	0.001
	Coking Coal	201687	3.170	3.004
	Brown Coal	61912	0.347	0.781
	Coke	24200	0.391	0.294
	Artificial Gases	22301	6.257	0.018
	Biomass	0	4.810	0.092
	Other	115	0.003	0.002
	Totals	*354654*	*37.340*	*5.755*
Fugitive Emissions from Fuels	Coal Production	-	798.735	-
	System of Crude Oil and Gas	52	195.146	-
	Totals	*52*	*993.881*	-
Industrial Processes	Iron Production	544	3.214	-
	Cement Production	5155	-	-
	Lime Production	2562	-	-
	Nitrid Acid Production	-	-	5.362
	Ammonia Production	3	9.614	9.810
	Soda Ash Production	24	-	-
	Other	0	0.227	0.970
	Food and Drink	924	-	-
	Totals	*9212*	*13.055*	*16.142*
Agriculture	Enteric Fermentation	-	793.255	-
	Manure Management	-	55.238	-
	Agricultural Soils	-	-	40.656
	Field Burning of Agr. Residues	-	1.478	0.075
	Totals	-	*849.970*	*40.731*
Land Use Change and Forestry	Changes in Forest and Other Biomass Stocks Abandonment of Managed Lands	-45448	-	-
	Forest and Grasslands Conversion CO_2 Emissions and Removals from Soils	785	0.235	0.002
	Totals	*-44663*	*0.235*	*0.002*
Waste	Solid Waste	-	766.920	-
	Industrial Waste Water	-	129.984	-
	Municipal Waste Water	-	9.676	-
	Totals	-	*906.580*	-
National Totals		***319255***	***2801.061***	***62.631***
GRAND TOTAL			**397493**	

Table B-3: Poland's emission estimates for 1999. Source: NEC (2001).

IPCC Specification	**Fuel**	**Emission [Gg]**		
		CO_2	**CH_4**	**N_2O**
Fuel Combustion Activities	Furnace Oil	11944	0.746	0.341
	Diesel Oil	19766	1.163	0.952
	Petrol	16011	5.857	1.082
	Aviation Fuel	684	0.023	0.043
	Other Petroleum Products	9622	0.685	0.182
	High Methane Natural Gas	15257	0.365	0.342
	Natural Nitrited Gas	2145	0.050	0.027
	Coking Coal	163397	5.263	2.624
	Brown Coal	57076	0.395	0.735
	Coke	12900	1.082	0.286
	Artificial Gases	10171	0.079	0.068
	Biomass	0	34.606	0.695
	Totals	*318973*	*50.315*	*7.378*
Fugitive Emissions from Fuels	Coal Production	-	585.993	-
	System of Crude Oil and Gas	125	191.382	-
	Totals	*125*	*777.375*	-
Industrial Processes	Iron Production	565	2.154	-
	Cement Production	7777	-	-
	Lime Production	1805	-	-
	Nitrid Acid Production	-	-	5.559
	Ammonia Production	2	5.640	5.755
	Soda Ash Production	400	-	-
	Other	57	0.187	0.752
	Food and Drink	-	-	-
	Totals	*10610*	*7.981*	*12.066*
Agriculture	Enteric Fermentation	-	469.223	-
	Manure Management	-	38.863	20.102
	Agricultural Soils	-	-	35.471
	Field Burning of Agr. Residues	-	1.218	0.056
	Totals	-	*509.304*	*55.629*
Land Use Change and Forestry	Changes in Forest and Other Biomass Stocks	-39767	-	-
	Abandonment of Managed Lands			
	Forest and Grasslands Conversion CO_2 Emissions and Removals from Soils	-3697	0.108	0.001
	Totals	*-43464*	*0.108*	*0.001*
Waste	Solid Waste	-	824.872	-
	Industrial Waste Water	-	68.317	-
	Municipal Waste Water	-	11.953	-
	Totals	-	*905.142*	-
National Totals		***286244***	***2250.225***	***75.074***
GRAND TOTAL			**356771**	

Appendix C

Table C-1: Relative uncertainties (95% confidence interval) of activity data.

IPCC Specification	Fuel	Relative Uncertainty of Activity			
		1st calculations		2nd calculations	
		[%]	Source	[%]	Source
Fuel Combustion Activities	Furnace Oil	5.2	Szukalski, 2000	5.2	Szukalski, 2000
	Diesel Oil	23.6	Szukalski, 2000	23.6	Szukalski, 2000
	Liquid Natural Gas (LNG)	40	Szukalski, 2000	40	Szukalski, 2000
	Petrol	13.6	Szukalski, 2000	13.6	Szukalski, 2000
	Aviation Fuel	60	Szukalski, 2000	60	Szukalski, 2000
	Other Petroleum Products	20	Szukalski, 2000	20	Szukalski, 2000
	High Methane Natural Gas	5.2	Szukalski, 2000	5.2	Szukalski, 2000
	Natural Nitrited Gas	2.2	Szukalski, 2000	2.2	Szukalski, 2000
	Other Natural Gases	20.6	Assumption	20.6	Assumption
	Coking Coal	1.4	Szukalski, 2000	2	Szukalski, 2000
	Brown Coal	1.4	Szukalski, 2000	1.4	Szukalski, 2000
	Coke	5.6	Szukalski, 2000	5.6	Szukalski, 2000
	Artificial Gases	10	Szukalski, 2000	10	Szukalski, 2000
	Biomass	40	Szukalski, 2000	40	Szukalski, 2000
	Other	7	IPCC, 1996	7	IPCC, 1996
Fugitive Emissions from Fuels	Coal Production	0.4	Szukalski, 2000	0.4	Szukalski, 2000
	System of Crude Oil and Gas	1	Szukalski, 2000	1	Szukalski, 2000
Industrial Processes	Iron Production	1.2	Szukalski, 2000	2	Assumption
	Cement Production	0.4	Szukalski, 2000	0.4	Szukalski, 2000
	Lime Production	2	Szukalski, 2000	2	Szukalski, 2000
	Nitrid Acid Production	1.2	Szukalski, 2000	2	Assumption
	Ammonia Production	1.2	Szukalski, 2000	2	Assumption
	Soda Ash Production	1.2	Szukalski, 2000	2	Assumption
	Other	1.2	Szukalski, 2000	2	Assumption
	Food and Drink	1.2	Szukalski, 2000	2	Assumption
Agriculture	Enteric Fermentation	10	Szukalski, 2000	10	Szukalski, 2000
	Manure Management	10	Szukalski, 2000	10	Szukalski, 2000
	Agricultural Soils	10	Szukalski, 2000	10	Szukalski, 2000
	Field Burning of Agr. Residues	60	Szukalski, 2000	60	Szukalski, 2000
Land Use Change and Forestry	Changes in Forest and Other Biomass Stocks Abandonment of Managed Lands	22	Szukalski, 2000	22	Szukalski, 2000
	Forest and Grasslands Conversion CO_2 Emissions and Removals from Soils	4	Szukalski, 2000	4	Szukalski, 2000
Waste	Solid Waste	46	Szukalski, 2000	46	Szukalski, 2000
	Industrial Waste Water	40	Szukalski, 2000	40	Szukalski, 2000
	Municipal Waste Water	60	Szukalski, 2000	60	Szukalski, 2000

Table C-2: Relative uncertainties (95% confidence interval) of CO_2 emission factors.

IPCC Specification	Fuel	Relative Uncertainty of CO_2 Emission Factor			
		1st calculations		2nd calculations	
		[%]	Source	[%]	Source
Fuel Combustion Activities	Furnace Oil, Diesel Oil	0.4	Szukalski, 2000	0.4	Szukalski, 2000
	Liquid Natural Gas (LNG)	6	Szukalski, 2000	6	Szukalski, 2000
	Other Petroleum Products	3.8	Szukalski, 2000	3.8	Szukalski, 2000
	Natural Gas	2.8	Szukalski, 2000	2.8	Szukalski, 2000
	Coal	3	Szukalski, 2000	3	Szukalski, 2000
	Coke	6	Szukalski, 2000	6	Szukalski, 2000
	Artificial Gases	4	Szukalski, 2000	4	Szukalski, 2000
	Other	7	IPCC, 1996	7	IPCC, 1996
Fugitive Emissions from Fuels	System of Crude Oil and Gas	13.2	Szukalski, 2000	13.2	Szukalski, 2000
Industrial Processes	Iron Production	14	Szukalski, 2000	14	Szukalski, 2000
	Cement Production	4	Szukalski, 2000	4	Szukalski, 2000
	Lime Production	5.0	Jonas and Nilsson, 2001	4	Assumption
	Ammonia Production	5.0	Jonas and Nilsson, 2001	4	Assumption
	Soda Ash Production	5.0	Jonas and Nilsson, 2001	4	Assumption
	Other	5.0	Jonas and Nilsson, 2001	4	Assumption
	Food and Drink	0.5	Jonas and Nilsson, 2001	4	Assumption
Land Use Change and Forestry	Changes in Forest and Other Biomass Stocks Abandonment of Managed Lands	22	Szukalski, 2000	22	Szukalski, 2000
	Forest and Grasslands Conversion CO_2 Emissions and Removals from Soils	60	Szukalski, 2000	60	Szukalski, 2000

Table C-3: Relative uncertainties (95% confidence interval) of CH_4 emission factors.

IPCC Specification	**Fuel**	**Relative Uncertainty of CH_4 Emission Factor**			
		1st calculations		**2nd calculations**	
		[%]	**Source**	**[%]**	**Source**
Fuel Combustion Activities	Furnace Oil, Diesel Oil	83.6	Szukalski, 2000	83.6	Szukalski, 2000
	Liquid Natural Gas (LNG)	34	Szukalski, 2000	34	Szukalski, 2000
	Other Petroleum Products	34	Szukalski, 2000	34	Szukalski, 2000
	Natural Gas	20.4	Szukalski, 2000	20.4	Szukalski, 2000
	Coal	27	Szukalski, 2000	27	Szukalski, 2000
	Coke	27	Szukalski, 2000	27	Szukalski, 2000
	Artificial Gases	27	Szukalski, 2000	27	Szukalski, 2000
	Biomass	48	Szukalski, 2000	48	Szukalski, 2000
	Other	7	IPCC, 1996	7	IPCC, 1996
Fugitive Emissions from Fuels	Coal Production	30	Szukalski, 2000	30	Szukalski, 2000
	System of Crude Oil and Gas	16.2	Szukalski, 2000	16.2	Szukalski, 2000
Industrial Processes	Iron Production	30	Szukalski, 2000	30	Szukalski, 2000
	Ammonia Production Other	10	Assumption	10	Assumption
Agriculture	Enteric Fermentation	42	Szukalski, 2000	42	Szukalski, 2000
	Manure Management	40	Szukalski, 2000	40	Szukalski, 2000
	Field Burning of Agr. Residues	30	Szukalski, 2000	30	Szukalski, 2000
Land Use Change and Forestry	Forest and Grasslands Conversion CO_2 Emissions and Removals from Soils	60	Szukalski, 2000	60	Szukalski, 2000
Waste	Solid Waste	62	Szukalski, 2000	62	Szukalski, 2000
	Industrial Waste Water	40	Szukalski, 2000	40	Szukalski, 2000
	Municipal Waste Water	22	Szukalski, 2000	22	Szukalski, 2000

Table C-4: Relative uncertainties (95% confidence interval) of N_2O emission factors.

IPCC Specification	Fuel	Relative Uncertainty of N_2O Emission Factor			
		1st calculations		2nd calculations	
		[%]	Source	[%]	Source
Fuel Combustion Activities	Furnace Oil, Diesel Oil	7.6	Szukalski, 2000	7.6	Szukalski, 2000
	Liquid Natural Gas (LNG)	40	Szukalski, 2000	40	Szukalski, 2000
	Other Petroleum Products	40	Szukalski, 2000	40	Szukalski, 2000
	Natural Gas	4.6	Szukalski, 2000	4.6	Szukalski, 2000
	Coal	23.4	Szukalski, 2000	23.4	Szukalski, 2000
	Coke	23.4	Szukalski, 2000	23.4	Szukalski, 2000
	Artificial Gases	23.4	Szukalski, 2000	23.4	Szukalski, 2000
	Biomass	74	Szukalski, 2000	74	Szukalski, 2000
	Other	7	IPCC, 1996	7	IPCC, 1996
Industrial Processes	Nitrid Acid Production Ammonia Production Other	70	Jonas and Nilsson, 2001	70	Jonas and Nilsson, 2001
Agriculture	Agricultural Soils	8	Szukalski, 2000	40	Assumption
	Field Burning of Agr. Residues	70	Szukalski, 2000	70	Szukalski, 2000
Land Use Change and Forestry	Forest and Grasslands Conversion CO_2 Emissions and Removals from Soils	60	Szukalski, 2000	60	Szukalski, 2000