Emission estimation of solid waste disposal sites according to the uncertainty analysis methodology

J. Szemesová [(1)] and M. Gera [(2)]

[(1)] Slovak Hydrometeorological Institute, Jeseniova 17, Bratislava, Slovak Republic (e-mail: janka.szemesova@shmu.sk)

[(2)] Faculty of Mathematics Physics and Informatics, Comenius University, Mlynska dolina, 842 48, Bratislava, Slovak Republic (e-mail: mgera@fmph.uniba.sk)

Abstract Slovak Republic, as the member of European Union and signature country of the UNFCCC and Kyoto Protocol is required to provide national inventory and reports on GHG emissions. One of the sectors identified as significant source of methane is disposal of waste to solid waste disposal sites (SWDSs). Methane emissions from the solid waste disposal sites are the key source and concerning to the actual emission factors there are estimated with the high uncertainty level. The emission uncertainty calculation of landfills by using the more sophisticated Tier 2 - Monte Carlo method is evaluated in this article. For this reasons the software package, which works with probabilistic distribution and their combination, was developed. The results, sensitivity analysis and computational methodology of methane emissions from solid waste disposal sites are presented.

Key words: *Monte Carlo method, methane emissions, solid waste and disposal sites*

1. Introduction

Climate change is one of the most serious global environmental problems. The international community and the general public have already understood the urgent need to tackle this problem. Moreover, the public is more and more witness and victim of the damage due to extreme heat, flooding and windstorms that Europe, North America, China, India, and the Caribbean were exposed frequently.

The instrument to tackle the problem of climate change is the UN Framework Convention on Climate Change adopted in 1992. The aim of the Convention is to stabilize atmospheric concentrations of greenhouse gases to a safe level. Currently, there are 185 countries or international communities, including Slovakia, and the EU that are parties to the Convention. The Convention requires the adoption of measures that aim to reduce the GHG emission to the level of the year 1990.

The unfavorable development and balance of GHG emissions generation since 1992 have created a need to adopt an additional and effective instrument. In 1997, the parties of the Convention agreed to endorse the Kyoto Protocol (KP) that defines reduction targets for countries of the Annex I to the Convention. Developed countries defined in Annex B of the Kyoto Protocol should individually or together reduce emissions of six GHG on average by 5.2 % from the level of the year 1990 during the first commitment period 2008 – 2012. The reduction target of the Slovak Republic is 8 % reduction of emissions compared to the base year 1990.

In May 2004, Slovakia joined the European Union. Relevant European legislation is expected to have additional positive direct and indirect effects to reduction of GHG emissions, mainly in the energy sector. The introduction of emission trading scheme will allow for the implementation of further reduction measures. The European Union considers the area of climate change for the one of the four environmental priorities.

The Slovak Republic submits the data about GHG emissions in the relevant extend to the January, 15. annually, according the Decision No. 280/2004/EC of the European Parliament and of the Council concerning a Mechanism for Monitoring Community GHG emissions and for implementing the Kyoto Protocol. According to the latest inventory, Slovakia has achieved a reduction of total anthropogenic emissions of greenhouse gasses expressed as CO_2 equivalent, of approximately 30 % compared the year 1990. This achievement is the result of several processes and factors, mainly:

- higher share of services in the generation of the GDP,
- higher share of gas fuels in the primary energy resources consumption,
- restructuring of industries,
- gradual decrease in energy demands in certain heavy energy demanding sectors (except for metallurgy),
- and the impact of air protection legislative measures influencing directly or indirectly the generation of greenhouse gas emissions.

The several COP/MOP decisions were adopted to implement methodology for GHGs inventory and national communication under UNFCCC. The following IPCC manuals are actually in utilizations: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventory, Volume 1-3 [1], Good Practice Guidance and Uncertainty Management in National GHGs Inventories 2000 [2] and IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry 2003 [3]. Slovak Republic, as the member of European Union and signature country of the UNFCCC is required to provide national inventory and reports on GHG emissions. One of the IPCC sectors identified as significant source of methane and key source is disposal of waste to solid waste disposal sites (SWDSs).

More complex method for estimating methane emissions from solid waste disposal sites (SWDSs) acknowledges the fact that methane is emitted over a long period of time rather than instantaneously. A kinetic approach therefore needs to take into account the various factors, which influence the rate and extent of methane generation and release from SWDSs. The equations presented in IPCC manuals form the base for first order decay (FOD) method kinetics and are quoted from the Revised 1996 IPCC Guidelines for National Inventories: Reference Manual. IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories provide further details on the FOD method, mainly in defining FOD model parameters in terms familiar to users of the default method Tier 1.

This approach can be used to model landfill gas generation rate curves for individual landfill. It can also be used to model gas generation for a set of SWDSs to develop country emissions estimates or can be applied in a more general way to entire regions.

The IPCC methodology and Good Practice Guidelines were used to estimate of methane emissions from landfill. Database of Center of Waste Service and Environmental Management in Bratislava have been used as a source of input data GHG emissions from the waste sector are the key source and concerning to the actual emission factors (EF) there are estimated with the high uncertainty level.

For better estimation of emissions it is considerable to follow the IPCC Guidelines and develop the country specific methodology for the waste sector. From government engagement it is important to test the preparedness of the Slovak Republic to prepare methane emissions estimation according to the method - Tier 2. There are three main challenges in the application of the Tier 2 method in the Slovak Republic:

- Selection of an appropriate FOD method - Tier 2;
- Preparation of activity data needed as input for the FOD method;
- Reflection of waste management practice changes in the period 1960-2005.

Emissions of methane from landfill were estimated with methodology First Order Decay (FOD) method Tier 2 according advises of the expert review team of UNFCCC secretariat and European Commission. All time series were recalculated until 1960 and the complete methodology approach was changed.

These three versions of FOD method were considered for the use as Tier 2 method for estimation of methane emissions from SWDS in the SR. Comparing the situation abroad with the situation in country, several differences can be identified:

- Most countries are using site-specific data. The methane emissions are calculated for each SWDS (or group of SWDS) separately and then the results are summed to obtain national methane emissions estimations. This approach is not yet possible in the SR, because collected data on municipal solid waste (MSW) do not include the needed characterization of SWDS,
- Historical data on MSW management and disposal are more detailed that data available in the Slovak Republic,
- Data on MSW fractions are collected in more systematic and regular way that is the practice in the Slovak Republic.
- As the most appropriate approach was selected the Second version of FOD method, as it is defined in the IPCC Good Practice Guidance. This decision is supported by following reasons:
- Parameters used are better defined and allow direct comparison with the Tier 1 method,
- Some of the parameters used are defined as time-variables. This allows modeling of the waste sector transformation in the Slovak Republic in the period 1992-2000.

Structure of required input data better corresponds with MSW data available for the Slovak Republic (data for the use of multiphase method are not available). The uncertainty of estimation of CH_4 emissions is mainly caused by uncertainty of statistical data on consumption. Another source of uncertainty is the applied default EFs. An additional error in calculation of the other greenhouse gas emissions may occur as a result of less exact methods and it cannot be estimated. The calculation emission uncertainty of landfill by using the more sophisticated Tier 2 - Monte Carlo method is evaluated in this article.

2. Tier 2 or Monte Carlo method

In the some cases the pure analytic solution of investigated problem is difficult to find. For events where significant inaccuracy of mentioned data is presented, the statistical approach is accepting and it help us to include uncertainty to the final assumption. To know the final margin of uncertainty is necessary for estimation of eventual fluctuation of analyzed variable. When to the process evaluation the combination of data with different uncertainty are entered to the result, with using a classical statistical approach it can be difficult in some cases to obtain reasonable final information.

One method, which allows us to implement all uncertainty to the final analyses, is Monte Carlo method. In many applications of Monte Carlo method, the investigated process is simulated directly. There is no need to describe the behavior of the investigated system, which can be advantages in some complicated systems. The only important requirement is that this system could be described by probability density functions (PDF). We will assume that the properties of a system can be described by PDF's. Once the PDF's are known, the Monte Carlo simulation can proceed by random sampling technique from the PDF's. This approach works with random number generator of random numbers, which have properties of desirable PDF. Many trials are then performed and the expected result is obtained as an average over the number of values. In this case, it can be predicted the statistical structure as are variance, kurtosis and some other higher statistical moments of this simulated result. From these characteristics the estimation of the number of Monte Carlo trials can be achieved to obtain a result with an expected error.

The Monte Carlo method is based on the generation of multiple trials to determine the expected value of a random value. In our case it can be said that this method is uncertainties combination of probability distribution functions for activity data (AD) and EFs. Total emissions are then computed as combination of random numbers for appropriate distribution function for assigned greenhouses gases. The advantage of this method is asymmetry allowance to the statistical distribution (Tier 1 method do not allow asymmetry). This advanced method is useful for data manipulation, in the case, when proper input data quality is provided.

3. Landfill methane emissions

For Monte Carlo simulation of CH_4 it was chosen second variant of FOD method. Details one can see in the publication [4]. There is important information that from solid waste disposal sites emissions of CH_4 are mainly dependent on the factors from inventory year (amount of waste storage, meteorological conditions, population growth, composition...) and from previous years (managing style of sites...). It is visible that total emissions are dependent to the many factors, which have time dependence. The formulas, which describe these emissions, have form:

$$L_0(x) = \frac{16}{12} MCF(x) DOC(x) DOCF(x) F(x),$$

$$Fk(x) = (1 - e^{-k}) e^{-k(t-x)},$$

$$MSWL(x) = MSWT(x) MSWF(x),$$

$$Q_t(x,t) = Fk(x,t) MSWL(x) L_0(x), \qquad (1)$$

$$Q_T(x) = \sum_x (Q_t - R(x))(1 - OX(x)) \qquad (2)$$

The meaning of abbreviation it can be seen in the table (1).

Q_t	methane generated in the year t (Gg/yr)
t	year of the inventory
x	years for which input data should be added
Fk	normalization factor which corrects the summation
k	Methane generation rate constant (1/yr)
MSWT(x)	Total municipal solid waste (MSW) (Gg/yr)
MSWF(x)	Fraction of MSW disposed in the year x
L_0(x)	methane generation potential (Gg CH_4/Gg waste)
MCF(x)	Methane correction factor in the year x (fraction)
DOC(x)	Degradable organic carbon in the year x (Gg C/Gg waste)
DOCF	Fraction of DOC dissimilated
F	Fraction by volume of the methane in the landfill gas
16/12	Conversion factor from C to CH_4
R(x)	Recovered methane in the inventory year t (Gg/yr)
OX(x)	Oxidation factor (fraction)

Table 1: Entered parameters to the function for methane emissions production

These formulas (1) and (2) one can interpreted that formula (1) and terms Q_t represent the contribution of emission from the waste layer imposed in the year 'x' to the year of inventory 't'. It means that result for inventory year 't' is computed by formula (2), which performs the summation of methane submission from different layer stored in different years.

To estimate the total emission for chosen year one can use our presented formulas. The situation starts to be complicated when people begin to assume input data uncertainty. The formulas (1) and (2) show relative complicated relation among the terms in these functions. The interaction of uncertainties starts to be hardly computed.

One can suppose that our emissions production is expressed by function $F(X_i)$, where X_i are factors, which affect the sequential result of emissions (i=1…N, N represents number for factors). Every factor has own uncertainty, which depend to the many sources. In some situation it is impossible to express variation of these sources to the function value. It is possible only express the interval of eventual values and their statistical behavior. In this case the values X_i can be interpreted as data set. For example factor X_1 will be represented with random values from expected range of values. The function value and their uncertainties it can be expressed:

$$F(X_i)=F(\overline{X}_i+\delta(X_i)), \tag{3}$$

where $\overline{X}_i$ could represent mean (expected value) or special chosen value from possible range of X_i values. It depends on solving algorithm, it will be specified later. Our question is how the uncertainties of X_i values will affect the function value $F(X_i)$. The interest is focused to find expression for $\delta(F(X_i))$.

Suppose that X_i are random variables. For example let X_1 has Normal distribution $X_1 \sim N(\mu_1,\sigma_1)$ and $X_2 \sim N(\mu_2,\sigma_2)$. There are independent random variables. For addition it can be expected: $F(X_1+X_2) \sim N(\mu_1+\mu_2, \sigma_1^2+\sigma_2^2)$. For multiplication the situation is complicated, suppose that $\mu_1=\mu_2=0$. For this situation the result can be written in the form: $F(X_1X_2) \sim \frac{1}{\sigma_1\sigma_2} J_0\left(\frac{|X_1X_2|}{\sigma_1\sigma_2}\right)$, where J_0 is a modified Bessel function of the second kind. For exponential distribution, which is a special case of a gamma distribution one can obtain after multiplication of exponential distribution a Weibull distribution: $X_1 \sim$ Exponential($\lambda^{-\gamma}$) then $F(X_1^{1/\gamma}) \sim$ Weibull(γ,λ). From these examples it is visible that direct computation of $\delta\,(F(X_i))$ is possible only in the special cases.

To estimate the properties of $\delta\,(F(X_i))$ it is possible to analyze the error propagation by linearized theory. Consider term groped with first derivative of Taylor's series for $F(X_i)$. It can be written:

$$|F(X_i)-F(\overline{X}_i)| \le \sum_i |X_i-\overline{X}_i| \left|\frac{\partial F(\overline{X}_i)}{\partial X_i}\right|,$$

or in equivalent form

$$\delta F(X_i) \cong \sum_i \delta(X_i) F'(\overline{X}_i) \tag{4}$$

With utilization the same approach it is possible to take the formula for variance:

$$\mathrm{Var}[\delta F(X_i)] \cong \sum_j \sum_i \mathrm{Cov}[\delta(X_i),\delta(X_j)] \left|\frac{\partial F(\overline{X}_i)}{\partial X_i}\right| \left|\frac{\partial F(\overline{X}_j)}{\partial X_j}\right| \tag{5}$$

This simplified approach allows us refuse complicated behavior of function $F(X_i)$ and compute their uncertainty as linear combination of their variables uncertainty, see formula (4). For variance, there is no linear relation, but when correlations among factors X_i are suppressed and $X_i \sim N(\mu_i, \sigma_i)$ then for $\delta(F(X_i))$ a noncentral chi-square distribution can be assumed.

This simple approach has limitation of applicability. It shows error spreading and it forms scheme of uncertainty interactions. Without the generality lose the formula (4) can be prescribed to the applicable form:

$$\delta F(X_i) \cong \sum_i \frac{\delta(X_i)}{\overline{X}_i} \left|\overline{X}_i F'(\overline{X}_i)\right|$$

or with introducing the new functions:

$$\delta F(X_i) \cong \sum_i \frac{\delta(X_i)}{\overline{X}_i} \left|G(\overline{X}_i)\right| \tag{6}$$

where $G(\overline{X}_i)=\overline{X}_i F'(\overline{X}_i)$. This expression shows linearized form of uncertainty combination. When $\delta(X_i)$ is substituted with value, which represents 95% confidence interval, ratio $\delta(X_i)/\overline{X}_i$ represents percentual contribution to the total uncertainty. The result is linear combination of these percentual submissions. From this is visible that linearized approach is effective to use only in the case when $|G(\overline{X}_i)|<<1$. On the other hand it shows us that PDF's of $\delta(X_i)$ can play important role within process of uncertainty combination. From this knowledge it is clear that one can not take simply errors from $\delta(X_i)$ and sum then together without to investigation of probability distribution function of $\delta(X_i)$. Initialization records application from our applied values to our FOD model confirm apprehension from linear theory limitations. Uncertainty result for total emissions exceeds about two times mean value. This result, as we will see after application more sophistical method, does not represent reality in our case, when uncertainty $\delta(X_i) \sim \overline{X}_i$. But it helps us to estimate uncertainty propagation in our formula.

The method Monte Carlo is convenient to use for uncertainty problem solving. One requirement is to know distribution function of uncertainties. This approach allows us, with using a power of computer machine, simulate the complete properties of the final probability distribution function $\delta(F(X_i))$ and obtain required statistical characteristics. In this point one should be attentive, how uncertainties are specified. In the case when measurement of data is available the situation is well solvable. In the case of data absence the special estimation is provided. There are special recommendation in the literature [1], how to proceed adequate results.

For this reasons the software package, which works with probabilistic distribution and their combination, was developed. With help of AuvTool software, they create useful tools for uncertainties estimation. In developed packages the next statistical distributions are supported: Gumbel, Exponential, Weibull, Lognormal, Uniform, Triangular, Beta, Binomial, Negative binomial, Chi-squre, Noncentral chi-square, F, Noncentral F, Gamma, T, Noncentral T, Normal and Poisson.

For specification of probability distribution of AD and EF there is variety of inputs. For two parameters distributions the mean value and values represented 95% confidence interval are directly expressed. For three parameters distribution there is place for tuning of 95% confidence interval.

To solve equations (1 and 2) with Monte Carlo method it is necessary to specify uncertainty of parameters, which have entry to our formulas. The profiles of PDF's function are obtained after expert consultation and IPCC Guidelines suggestions. Result of setting PDF's efforts is summarized in the tab. (2).

In the tab. (2) some parameters value should be explained. The parameter 'F', which one can see in the equations (1 and 2), is split to the variable 'FO' and 'FN'. The variable 'FO' represents bigger uncertainty, which was observed until year 1994 and 'FN' uncertainty, which was observed after year 1994. Analogical are defined parameters 'MCFN' and 'MCFO'. Difference from previous case is that mean value is changed too. For this reason 'MCFO' is valid until 1993 and among the years 1994 and 2001 the mean value is linearly interpolated among the values 'MCFN' and 'MCFO'. After year 2001 the value 'MCFN' from table is valid. Special explanation required parameter 'MSVL', which is a product of multiplication of 'MSWT' and 'MSWF'. From table (2) it seems that 'MSVL' produced negative contribution to the final emissions. This is not true. In this table we exploit the possibility easy transform the standard normal distribution to the normal distribution.

Category	Mean value	min/max	Distr. fun.
K	0.065	0.0357: 0.2145	triangular
FO	0.500	0.4000: 0.6000	triangular
FN	0.500	0.0000: 0.6000	triangular
MSVL	0.000	-1.9590: 1.9590	normal
DOCF	0.600	0.4200: 0.7680	triangular
DOCX	0.120	0.0600: 0.1440	triangular
MCFN	1.000	0.7000: 1.0000	triangular
MCFO	0.600	0.3000: 0.9600	triangular
OX	0.050	0.0025: 0.9750	normal

Table 2: Probability distribution functions and their basic characteristics, mean value and 95% confidence interval expressed with two values min. and max. The units of parameters are defined in table (1)

Parameter 'MSVL' is varied during analyzed period 1960-2005 significantly, the mean value and 95% confidence interval is varied during this period, but PDF has feature of the normal distribution. The uncertainty of 'MSVL' until 1995 was taken to 50% of the mean value. After 1995 the uncertainty of 'MSVL' was taken to 10% of the mean value. Variation of mean value of 'MSWL' it can be seen on the fig.(1). 'DOCX' value is linearly changed from value 0.06 in 1960 to value 0.12 in 1990. After year 1990 this parameter has constant value. For the parameter 'OX', the values from table are valid only in the period 1994 to 2005. Behind this time the zero value is assumed.

Specification of the parameters value is not a main topic of this article. Presented values are for illustration, more details about FOD model one can obtain in the article [4]. The main goal of this contribution is uncertainty specification and also type specifications of distribution function belong to parameters.

After application of Monte Carlo method to the FOD model the final probability distributions are obtained for every spotted year. This approach allows us to see detailed variation and combination of input parameters and their distribution functions. As was shown interaction of PDF's are not simple.

To see the influence of PDF's change to the total emissions, we try to modify PDF's profiles for every input parameter, which were defined in tab (2). Every profile in beginning of our analysis was changed to the normal or uniform distribution. The mean values were retained. Uncertainties were changed, the symmetrical uncertainties were setting in the first step of analysis for input parameters. In the table (3) first four rows represent this assumption. Abbreviation "Nor." expresses normal distribution and abbreviation "Uni." represents uniform distribution. Followed number express symmetrical uncertainty specification for all parameters, which contribute to the total methane emission (for example number 10 means that parameter "K" and other parameters are varied ±10% about mean value). Last two rows ("Uni. Tab" and "Tabular") use uncertainty parameters setting from tab. (2). "Uni. Tab" use uniform PDF setting instead predefined PDF, "Tabular" uses PDF and uncertainties from tab (2).

Result for PDF's exchange it can be seen in the tab. (3). After Monte Carlo simulation with 20 000 trials the followed results are obtained. The mean value and average for total emissions are not change significantly. Whereas other statistic characteristics are changed significantly. This result shows dependence to the sort of PDF's and it calls for tidy approach in PDF's selection.

CH4/Param	median	average	st. dev.	2,50%	Percent	97,50%	Percent	Abs.Min	AbsMax
Nor.10	49.22	49.47	5.67	39.09	-20.98	61.33	23.97	32.97	77.63
Nor.50	43.87	48.75	26.47	12.04	-75.30	113.00	131.79	0.67	241.47
Uni.10	49.09	49.45	6.37	37.98	-23.20	62.98	27.36	31.91	73.39
Uni.50	41.18	48.45	29.79	11.49	-76.28	125.88	159.81	4.50	212.33
Uni. Tab	38.41	40.03	13.02	19.54	-51.19	69.19	72.85	12.99	90.86
Tabular	42.98	43.56	10.18	25.45	-41.57	64.81	48.78	16.77	84.37

Table 3: Statistical characteristics for different PDF setting for year 2005, mean value (Gg/yr), average (Gg/yr), standard deviation (Gg/yr) and 95% confidence interval is expressed with two relative percentual values 2,50% and 97,50%. On the next absolute minimum and absolute maximum is shown.

Results for sensitivity of input parameters are simply verified. It can be seen in the tab. (4).

CH4/Param	median	average	st. dev.	2,50%	Percent	97,50%	Percent	Abs.Min	AbsMax
DOCX	43.23	48.46	25.36	14.04	-71.03	110.64	128.33	6.36	165.66
MCF	43.38	48.47	25.17	14.37	-70.34	110.31	127.61	7.45	160.46
K	42.26	49.51	30.09	11.95	-75.85	127.81	158.15	5.00	219.07
F	43.24	48.46	25.47	14.14	-70.83	110.91	128.85	6.92	165.97
DOCF	43.33	48.41	25.32	14.41	-70.24	110.16	127.56	6.35	167.57
MSVL	41.22	48.44	29.64	11.58	-76.10	125.14	158.31	4.42	205.30

Table 4: Statistical characteristics for uniform PDF setting for different parameters setting, parameter sensitivity is analyzed for year 2005, mean value (Gg/yr), average (Gg/yr), standard deviation (Gg/yr) and 95% confidence interval is expressed with two relative percentual values 2,50% and 97,50%. On the next absolute minimum and absolute maximum is shown. For total uncertainty computation every input parameters have ±50% uncertainty, except parameter, which is in the first row of this table. Uncertainty of this parameter is only ±5% above mean value.

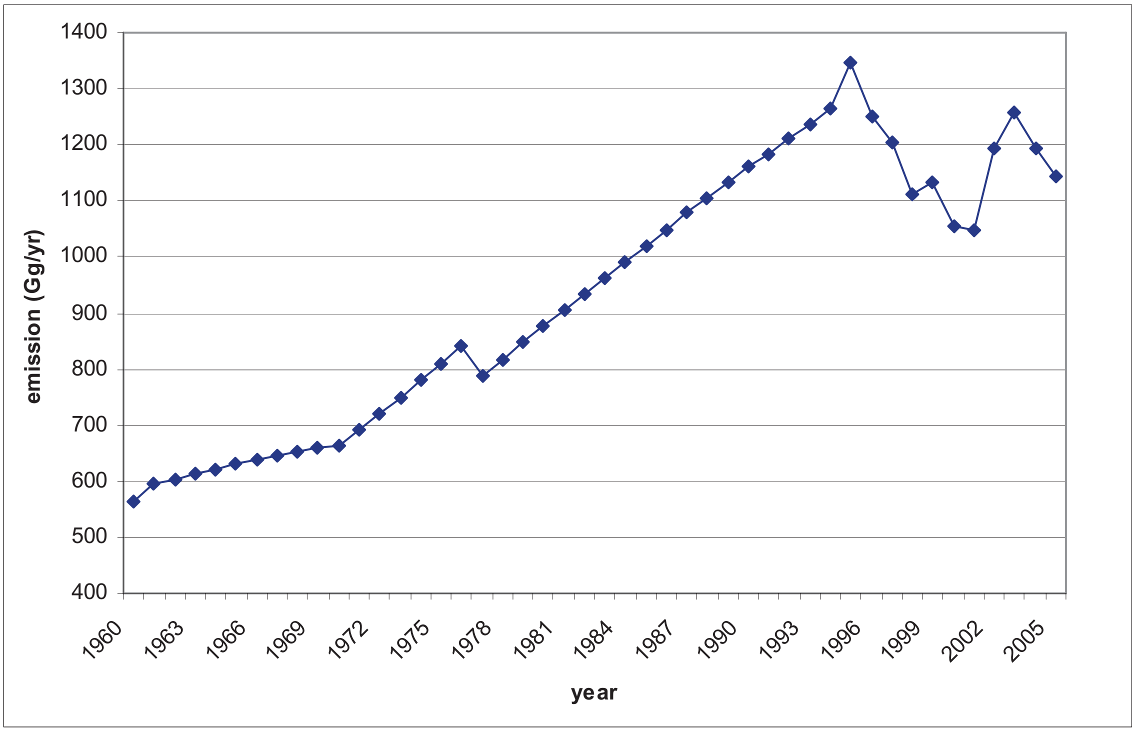

Figure 1: Municipal solid waste (MSWL) mean value variation during the period 1960-2005.

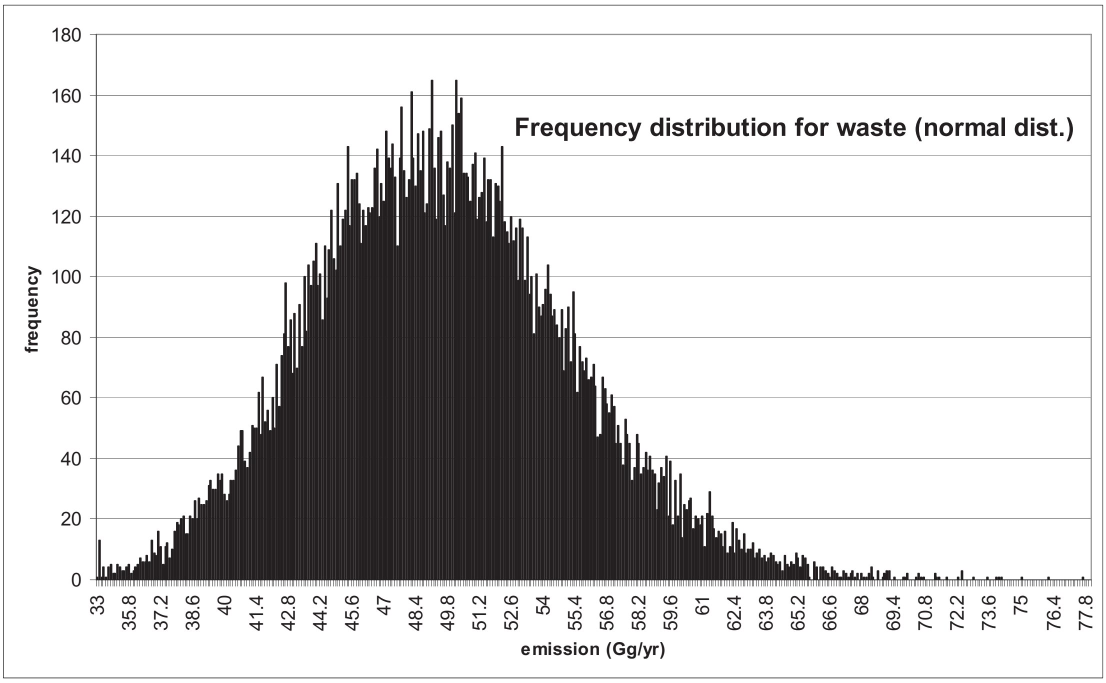

Figure 2: Total emission of CH_4 for the year 2005 for normal parameters distribution with 10% uncertainties for all parameters

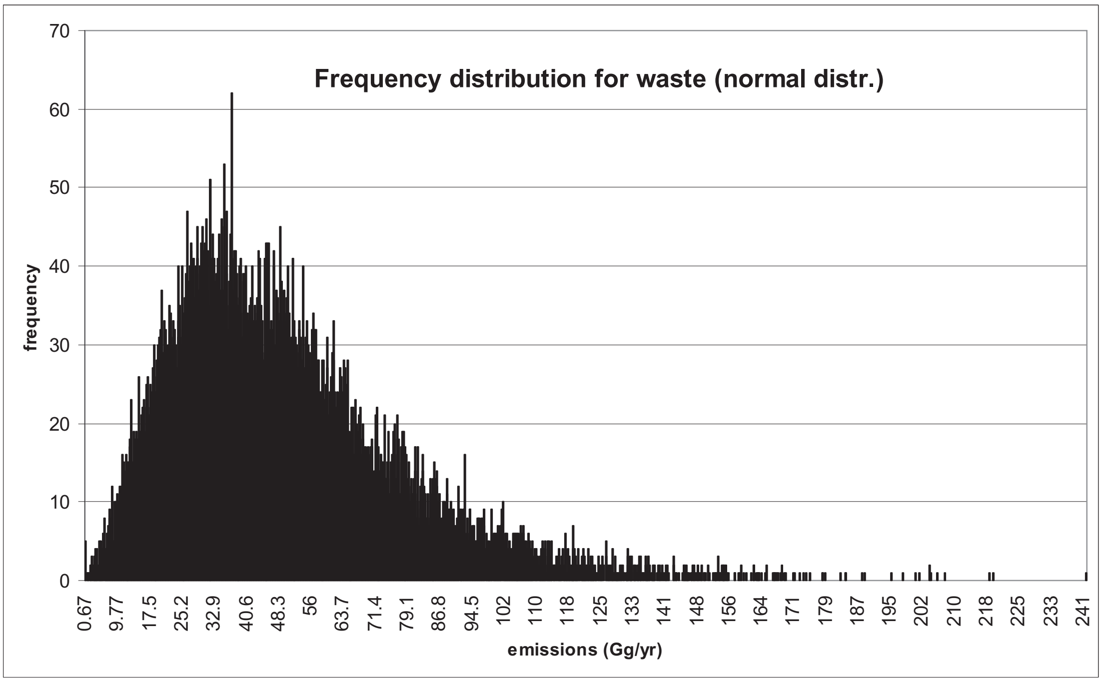

Figure 3: Total emission of CH_4 for the year 2005 for normal parameters distribution with 50% uncertainties for all parameters

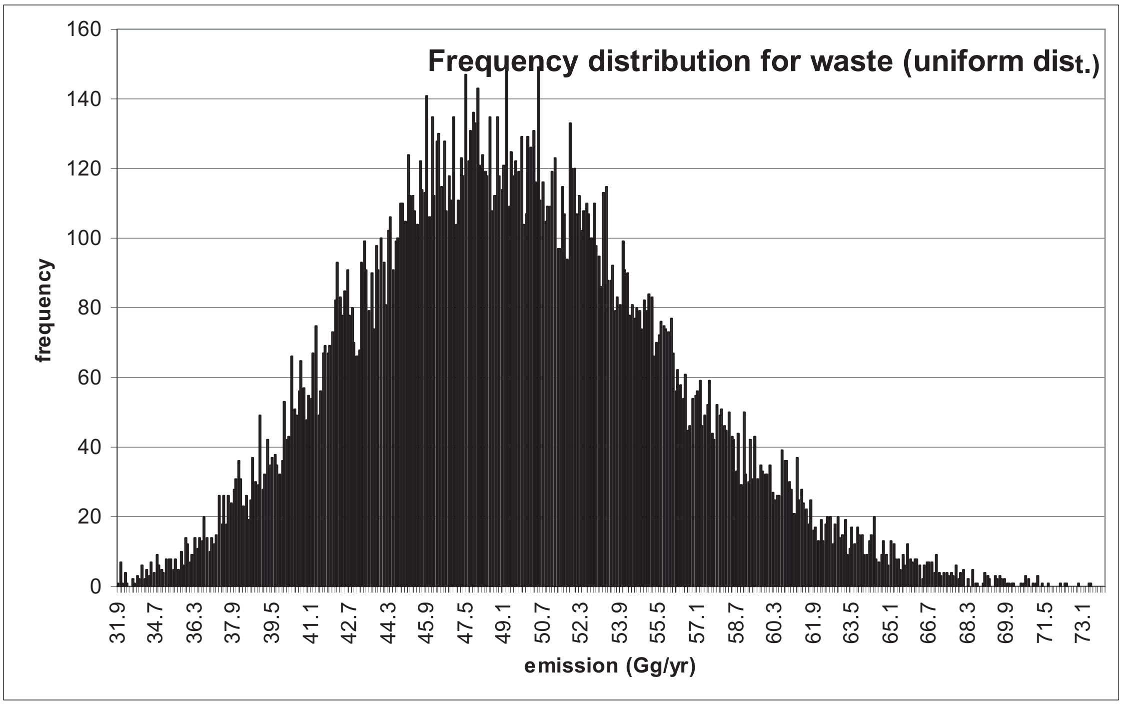

Figure 4: Total emission of CH_4 for the year 2005 for uniform parameters distribution with 10% uncertainties for all parameters

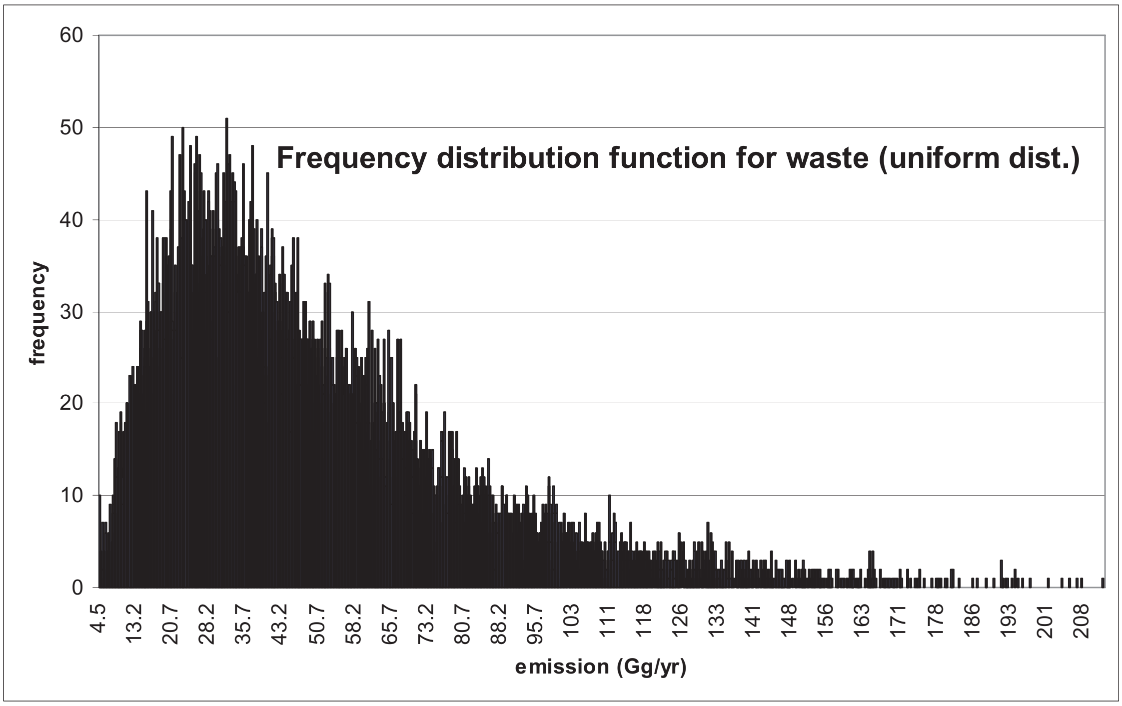

Figure 5: Total emission of CH_4 for the year 2005 for uniform parameters distribution with 50% uncertainties for all parameters

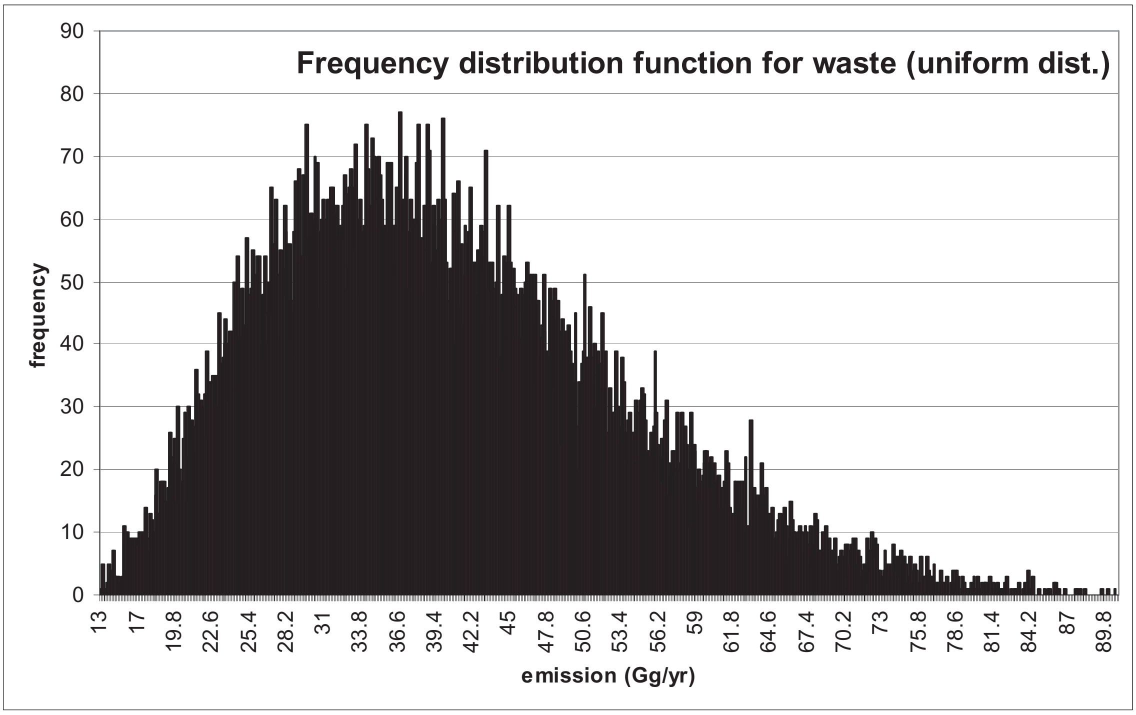

Figure 6: Total emission of CH_4 for the year 2005 for uniform parameters distribution with uncertainties setting from Tab.2.

From Fig. (2-6) it can be seen the total methane emission variability for year 2005. The main statistical results are summarized in the tab. (3). As was expected, the data accuracy play important role to the total uncertainty. PDFs selection in the case of symmetry uncertainty has less significant influence to the total uncertainty. Increasing of partial uncertainties for input factors multiple total uncertainties in the symmetrical cases. In the case of asymmetry, total uncertainty could be smaller than uncertainties of single input parameters. On the next we try to analyze parameter influence to the total emissions. For this reason comparison of tab. (3) and tab. (4) is done. It is convenient to compare row "Uni.50" with chosen statistics from tab. (3) and statistics in the tab. (4). Every rows in the tab. (4) show relevant parameter influence to the total emission computation. It can be seen that variation of parameter "K" and parameter "MSVL" have not significant influence to the total emission. This result was obtained with uniform PDF setting for all parameters and with change of uncertainty level from ±50% to ±5% for given parameter. Other parameters show similar dependence to the uncertainty of total emission. This approach shows that more important feature which has strongest influence to the total uncertainty in our formula is asymmetry allowance. The normal distribution does not allow asymmetry and for this reason one can see disadvantage of Tier 1 method which works with symmetric uncertainty. For this reason it seems that better choice of uncertainty specification is using simple PDF in the case of absence of measured data. For example triangular PDF, which allow asymmetry, has features, which help us to better compute total uncertainty.

With respect of obtained knowledge the final distribution function for total methane emission for chosen year 2005 it can be seen in the fig. (7). This result is for 20000 trials. A number of trials have influence to the result precision. Complete statistical characteristics as mean value, median, standard deviation and 95% confidence interval are presented in the Fig. (8) for 45 years period. For last seven years tab. (5) is added to more specify results.

Many parameters go into a place to the formulas (1) and (2). Each parameter uncertainty has different sensitivity to the computation of total uncertainty. In this article these features were not examined to deep details. For example parameter "K" has dependence to the amount of precipitation. In consequence of climatic changes the precipitation allocation (temporal distribution during the year and spatial distribution) will be changed.

CH_4/Yr	1999	2000	2001	2002	2003	2004	2005
median	39,511	39,339	39,162	44,608	47,099	44,899	42,979
average	40,056	39,884	39,710	45,219	47,739	45,503	43,558
st. dev.	9,360	9,378	9,324	10,603	11,181	10,646	10,182
2,50%	23,381	23,225	23,162	26,404	27,893	26,599	25,454
Percent	-41,629	-41,769	-41,672	-41,608	-41,571	-41,545	-41,563
97,50%	59,782	59,490	59,210	67,350	71,069	67,730	64,806
Percent	49,247	49,156	49,105	48,943	48,868	48,846	48,780
Abs.Min	14,826	15,306	15,250	17,377	18,357	17,506	16,765
AbsMax	77,227	77,048	76,668	87,385	92,336	88,079	84,375

Table 5: Statistical characteristics for last seven computed years, mean value (Gg/yr), average(Gg/yr), standard deviation (Gg/yr) and 95% confidence interval is expressed with two values 2,50% and 97,50%. Relative percentual values related to the mean value are presented too. On the next absolute minimum and absolute maximum is shown.

In the future the different scenario for north part and for south part of Slovakia is appeared. More than 30% variation to the current state of precipitation will be expected. The duration of arid and wet seasons will be changed too. These conditions will have influence to the processes in the disposal sites. It can make the influence to the mean value of parameter "K", or it can change the uncertainty of this parameter and consecutive it can have influence to the total methane emissions in the future. This assumption is valid in spite of low sensitivity for parameter "K" to the total emission uncertainty in our formulas.

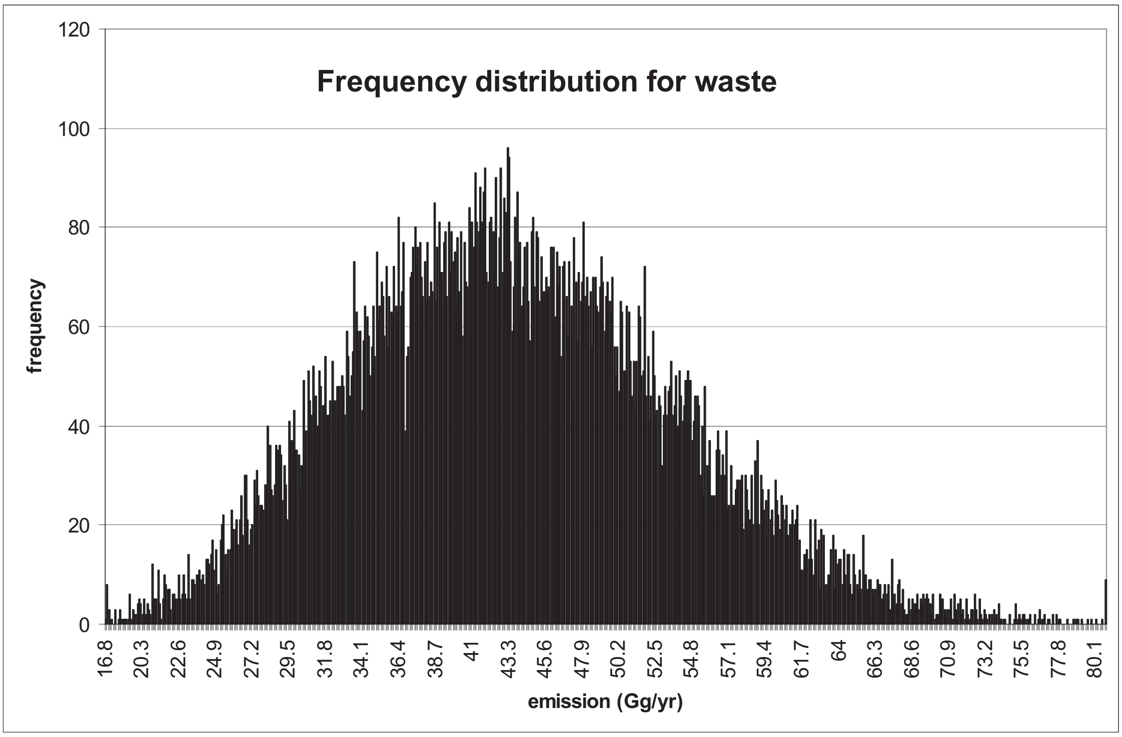

Figure 7: Total emission of CH_4 for the year 2005 for parameters settings from Tab.2.

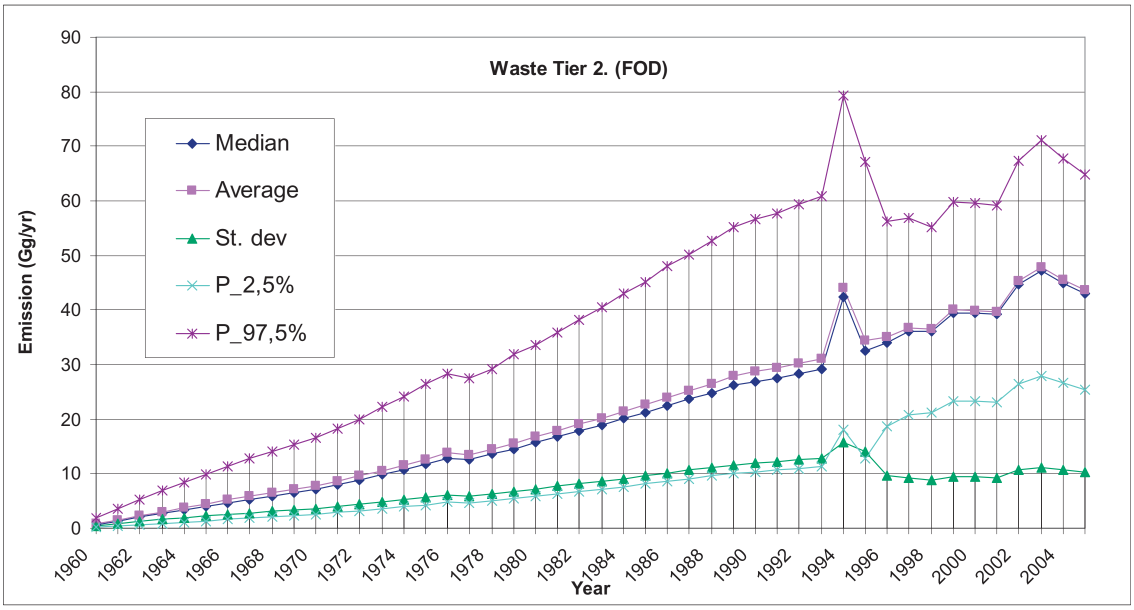

Figure 8: Variation of median, average, standard deviation and 95% confidence interval expressed by min. and max. values during the period 1960-2005.

4. Conclusion

The main topic of this article was to eliminate uncertainty of methane emissions produced by solid waste disposal sites. From our analyses seems that uncertainty of emissions are strongly dependent to the PDF's setting. These features were identified by simplest linear analyses of uncertainty of total emissions and in the second case with changing PDF's setting. The data accuracy play important role to the computation of the total uncertainty. PDFs selection in the case of symmetry uncertainty has no significant influence to the total uncertainty. Increasing of partial uncertainties for input factors multiple total uncertainties in the symmetrical cases. In the case of asymmetry, total uncertainty could be smaller than uncertainties of single input parameters. It can be seen that variation of parameter "K" and parameter "MSVL" have not significant influence to the total emission. This result was obtained with uniform PDF setting for all parameters and with change of uncertainty level from ±50% to ±5% for given parameter. Other parameters show similar dependence to the uncertainty of total emission. This approach shows that more important feature which has strongest influence to the total uncertainty is asymmetry allowance. The essential result from our study is fact that total uncertainty was reduced comparable to IPCC default recommended value. This value is 50% for total methane emissions from SWDS. This default uncertainty is applicable to the Tier 1 default method. From this value in the Tier 1, the key sources are identified by categories magnitude, which adds up to over 95% of the total emissions or emission trend. In Tier 2 the 90% of the level or trend uncertainties are also taken for the key sources specification. Specification and identification of the key sources are important for economy and government institutions to obtain overview of emissions unload. During the uncertainty computation, the emitting of CH_4 from underlayer and many other factors as meteorological condition, managing of sites are included. These dependences are expressed in FOD model, which was solved by Monte Carlo simulation. Spreading of emission uncertainty during the analyzed period was obtained. From the computed result precision increasing of emissions are observed. In spite of high inaccuracy on the input data in the beginning of the examined period (this uncertainty has influence to the current uncertainty) the relative valuable result are obtained.

References

[1] Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventory, Volume 1-3, http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm/, IPCC 1996

[2] Good Practice Guidance and Uncertainty Management in National GHGs Inventories, http://www.ipcc-nggip.iges.or.jp/public/gp/english/, IPCC 2000

[3] IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry, http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm/, 2003

[4] Integrated Skills Ltd., Farkaš, J. Methane emissions from solid waste disposal sites in 2005, Bratislava, 2006