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A New Approach Method of CH_4 Emission Estimation from Landfills Municipal Solid Waste (MSW)

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Abstract

The CH_4 is one of the six Greenhouse Effect Gases **(GEG)** that is mentioned in *the Kyoto Protocol*. The GEG is generated by the anthropic activities which are conducive to climate changes if their management is not conducted in a proper way. The main purpose of the environment policy is the reduction of the **GEG** emission. It is well-known that the CH_4 gas emission from municipal solid waste **MSW** landfills is responsible for **4 ÷ 5%** of the total Greenhouse Effect. It is necessary to have a practical method to calculate the quantitative CH_4 gas emission, in order to apply an efficient management of the CH_4 gas emission from **MSW** landfills, conforming or non-conforming. This method has to be transparent, credible, coherent, and applicable both for conforming and non-conforming **MSW** deposits. This paper proposes a new estimation calculation method of the CH_4 gas emission from all **MSW** deposits in Romania. The IPCC group of experts has made recommendations related to the estimation of CH_4 but the European Union (EU) admits that the environmental conditions are not the same in every Member State. The annual evolution of CO_2 for the CH_4 gas emission at every **MSW** location is valuable information for the Environment Authority with a view to realistic environmental planning and for an efficient policy to be applied in order to reduce the greenhouse effect of **MSW** landfills.

Keywords

Ecological Condition, GEG, Landfill, MSW, Urban Area

1. Introduction

In May 2013, the United Nations (UN) adopted the *KYOTO Protocol* [1] relating to the pollution emission agents and the transfer registers (based on the so called *PRTR Protocol or Kiev Protocol*) [2] together with the UN Convention on climate changes.

This Convention is referring, among others, to the landfills having a daily activity of more than 10,000 tons/day ***MSW*** which amounts to more than 450,000 tons/year. For these *MSW* landfills, starting with 2007, *the individual* $\mathbf{CH_4}$ emission rate [3] has to be calculated and the results have to be communicated to the public. EU has adopted the European Emission Register in order to be in conformity with the PRTR Protocol. This Register provides some criteria to be fulfilled: *transparency*, *coherence*, *the possibility to compare results*. These criteria are a condition for the calculated results to be accepted into a national data base. Romania has adopted the UN PRTR Protocol and for the ***MSW*** landfills with more than 10,000 tons/day, the CH_4 emission will be included in a register. The Member State governments have to report all aspects related to the Climate Changes [3] to an inter-governmental group.

It is very clear that a method to estimate the CH_4 methane gas emission from *MSW* landfills is absolutely necessary [3].

This method has to cover the calculation of the CH_4 emission from both conforming and non-conforming *MSW* Romanian landfills [4] [5]. This method was applied for the CH_4 emission calculation of 13 *MSW* landfills—conforming and non-conforming. In this paper the calculated values for CH_4 emission [4] [5] [6] and the equivalent CO_2 for 1 non-conforming and for 2 conforming landfills are presented.

Analyzed landfills are located in Satu Mare, Ilfov and Bucharest municipality, Romania. The proposed method has a high degree of efficiency.

The CH_4 emission calculus for those 13 Municipal landfills (*msw*) and the drawing up adjacent graphics related to the equivalent of CO_2 demonstrate that the GEG is present. The Romanian Environmental Authorities have to act on this matter and to acknowledge about the GEG intensity and its duration [7], in the same time.

The Proposed method allows us the quantitative evaluation of CH_4 emission to be used as a natural energy source. Within the actual management of wastes only the sort of wastes having economical energy value is applied, according to the Europe Council provisions. It is to be mentioned also that only 20% of the generated wastes is sorted. In the deposit body, they are not included: metallic wastes, plastics, tires, recyclable wood or with energetic value, paper wastes and recyclable cartoon. It is to be mentioned also that, from information delivered by the local source, within the landfill body they are not included: inert wastes (construction and demolition), plastics, soils and stones, asbestos; the total contents of these wastes are not considered to be more than 10%.

I have to make a remark: the drawing up graphics were obtained by manual calculation rather than using specific software.

2. Present Situation

All types of wastes were deposited together [4], in specially designated *MSW* deposit areas, those coming from the anthropic activities as well as those generated by the agriculture and live-stock farm activities, e.g. animal and bird dejections. The bio-degradable wastes (rubbish) generated by intensive agriculture have to be taken into consideration as well.

The problem of the global warming and the obligation to apply the Kyoto Convention requirements involve the fulfillment of the rules regarding the limitation of the *MSW* gas emission [7] and the prohibition to have *MSW* landfills which do not comply with the rules of environmental protection [2].

Since 1999 Romania has started to have *MSW* landfills, in ecological condition, in accordance with the European regulation in the field, and, from 2007, when Romania adhered to the European Union (EU), all the *MSW* landfills have to respect, strictly, the EU legislation, as provided within the 75/442/CE Directives [5] [8] provisions.

This Directive [5] [8] was adapted [4] to the Romanian legislation by Government Decision [4] order no. 349/2005.

3. Estimative Methods for Ch4 Gas Emission Calculation

The quantity of the CH_4 gas emission from *MSW* landfills can be estimated, by calculus applying two methods, as follows:

METHOD No. 1

IPCC 2006 Method-Default Method (DM).

This method supposes that a non-dangerous ***MSW*** deposit will generate [9] [10], within a year, a certain quantity of $\mathbf{CH_4}$ and, in the next year, it will be a new amount of $\mathbf{CH_4}$ This method will not take into consideration the hypothesis that an *MSW* deposit is a conglomerate mixed wastes one (see Table 1). Another factor to be taken into consideration is the time-the basic factor for **GES** emission [10]. Different *MSW* components are gradually, deteriorated in time, so $\mathbf{CH_4}$ and $\mathbf{CO_2}$ as well as the non-methane gases, and are generated.

In order to illustrate results due to the method 1 use, the conform ***MSW*** calculus equations regarding $\mathbf{CH_4}$ emission [10] [11] will be indicated, as follows.

These calculus equations are:

Table 1. The percentage (%) composition of the ***MSW*** landfills.

Description of the composition of *MSW* landfills	Percentage [%]
Bio from kitchen, cantina's + animal manures, bio-wastes + market wastes + street wastes	51.2 ÷ 60
Rubbish from gardens and parks	16 ÷13
Paper + cartoon non-recyclable	14.2 ÷12.2
Non-recyclables woods and straws	3 ÷4,1
Non recyclable-textiles	2.6 ÷1.3
Sludge	1 ÷3
Industrial wastes (similar to home wastes) + sterilized medical wastes	12 ÷6.4

$$CH_{4(Gg/year)} = \left[\left(MSW_f * MSW_{F*}L_0\right) - R\right] * \left[\left(1 - 0X\right)\right]$$

where:

• L_0-CH_4 **generated** potential $\left(G_gC/G_gMSW\right)$ which depends by the *MSW* morphological composition it will be calculated by using the following relation, [7] [11];

• ***R***-CH_4 recovered at the inventory year of $\left(G_gC/G_gMSW\right)$, the recommended value, supposing that CH_4 is burned and not collected; if not, the recovered quantity of CH_4 calculated by using this method will be reduced from the CH_4 generated quantity.

• **0X-oxide** factor having a fractionary values-**0** for non-conforming deposits and **0.1** for the well arrangements (conforming) deposits.

$$L_{0(GgC/GgMSW)} = \left[MCF * DOC_f * F * 6/12\right]$$

CH_4 generated potential, where:

• ***MCF***-CH_4 correction factor, whose values are dependent by the location and the management of *MSW*;

• ***DOC$_f$***-the ***DOC*** dissimilated fraction-**0.55** having values within the interval **0.5 ÷ 0.6;**

• ***F***- CH_4 fraction part-from deposit gas (LFG) [5], given value is 0.5;

• **16/12-the *C*** conversion coefficient within CH_4;

The Dissolved Organic Carbon (*DOC*) is determined [11] [12] by using the relation:

$$DOC_{(GgC/GgMSW)} = \left(0.4 * A\right) + \left(0.17 * B\right) + \left(0.15\left(C\right) + \left(0.3 * D\right)\right)$$

where:

• ***A***-the ***MSW*** fraction represented by paper and non-reciclable textiles [6] [10] [13] [14].

• ***B***-the ***MSW*** fraction represented by garden and parks wastes, and other bio-degradable organic wastes, excepted food wastes [6] [10] [13] [14].

• ***C***-the ***MSW*** fraction represented by food wastes and other bio-degradable wastes, [6] [10] [13] [14];

• ***D***-the ***MSW*** fraction represented by woods or straw wastes, [IPCC], [6] [10] [13] [14];

This method has the following difficulty:

-Don't take into consideration that in the last 6 months deposited ***MSW*** are not degradable

-The CH_4 emission quantity is very high (inadmissible)

It is supposed that a ***MSW*** landfill will generate, within a year, a certain amount of CH_4 gas emission which can be estimated [10]. This method doesn't take into consideration the hypothesis that a ***MSW*** landfill is a mixed conglomerate of wastes (rubbish).

Another factor to be considered is the **time** which is the basic factor for CH_4 gas emission [10]. Different components of the ***MSW*** landfill are, gradually, degraded in time, and CH_4, other gases are produced [6].

METHOD No. 2

I developed a new calculation method for the methane gas emission estimation, from the Romanian waste landfills [7] [11], method called: "***DANILA VIERU METHOD FOR A CONFORMING AND NON-CONFORMING MSW LANDFILLS*** CH_4 ***GAS EMISSION ESTIMATION IN ROMANIA, BY CALCULUS***".

According to the above- mentioned method, it is assumed that the waste (rubbish) from ***MSW*** landfills will be gradually degraded [11] based on the following factors [10] [12]:

- Structure of the wastes (rubbish) composition;
- Environmental factors existing in that area;
- The thickness of the waste (rubbish) layer;
- The compacting grade (level);
- The depth of the place where the *MSW* is located;
- Time passed from the first deposition of wastes (rubbish).

Due to the ***time factor***, this method was called: "***DANILA VIERU METHOD FOR CONFORMING AND NON-CONFORMING MSW LANDFILLS*** CH_4***GAS EMISSION ESTIMATION IN ROMANIA, BY CALCULUS***".

The *IPCC-International Experts Group on Climate Change* makes recommendation [9] related to the use of some coefficients concerning the estimation of $\mathbf{CH_4}$ gas emission from *MSW* landfills but no to the use a specific calculus formula.

In the case of a ***MSW*** conglomerate landfill, having a broad range of types and amounts of wastes (rubbish), Romania did not possess an adequate (proper) formula for the ***MSW*** CH_4 gas emission estimation up to the year of 2012. The statistics of the wastes (rubbish), under the rule of the

Regulations no. 2150/2002 on waste statistics [17] do not solve the problem of the composition of the waste (rubbish) from *MSW*. The use of waste statistics assumes that the waste (rubbish) should be analyzed by means of a representative sample of economic operators and human agglomeration [12].

Taking into consideration that every district of Romania has approx. 200 economic operators and urban agglomeration we shall have approximately 8400 economic operators, in total [9].

Approximately 500,000 economic operators are assumed to be in the country which means that statistics representation will cover only 1.6% of the total country economic operators. This fact is quite unacceptable.

DESCRIPTION OF"***DANILA VIERU METHOD FOR CONFORMING AND NON-CONFORMING MSW LANDFILLS*** CH_4 ***GAS EMISSION ESTIMATION IN ROMANIA, BY CALCULUS***"

The method: ***"Danila Vieru method for conforming and non-conforming MSW landfills*** CH_4 ***gas emission estimation, in Romania, by calculus***", makes use of the following formula:

$$CH_4\left(Gg/\text{year}\right)_T = Q_{\text{mswdegrad}.T} * \%TDOC_{\text{dissolved}.T} * DOC_f * 16/12 * F * F_r, \quad (1)$$

This formula (equation) has some advantages, e.g.:

1) The hierarchy [6] of degraded ***MSW***, ***IN TIME***, under the environmental factors [atmospheric precipitations, annual average temperature, alternating periods of rain and drought, freezing and non-freezing periods, the degree of *MSW* compression, the thickness of waste (rubbish) layers, etc. [13];
2) The use of time periods for the degradation of ***MSW***;
3) The use of IPCC recommendation related to the application of the methodology calculation formula of CH_4 gas emission from ***MSW*** landfills;
4) Taking into consideration the specific environmental conditions of every district of Romania;
5) The specific economic conditions of every district, such as: industrial development, hand-made production, various branches of agriculture, etc. are taken into consideration;

It is well-known that CH_4 methane is a specific gas, and its contribution (percentage) to global warming is about 4 ÷ 5% so that the need for the quantification of CH_4 gas emission is imperative. In the meantime, measures to reduce the contribution of the CH_4 gas emission from ***MSW*** landfills have to be taken into account.

In July 16, 2009, due to the presence of non-conforming *MSW* landfills in Romania, some of them are closed while others will be in transition periods, in the case of ***MSW*** landfills, the emission of CH_4 methane gas will continue even after the closing period of non-conforming ***MSW*** landfills until approximately the year 2017. Before wastes (rubbish) are deposited within the body of ***MSW*** and a rational sorting have to be are done.

After the closure of ***MSW*** landfills, the quantity of the CH_4 gas emission will decrease but still will continues to exist [14]. Following the legal conditions for opening a new ***MSW*** landfill it is absolutely necessary to know the evolution of CO_2 (in equivalent), the location of the new ***MSW*** landfill and the potential impact over the environment. As it is known, in approximately 10 years, the warming effect will be intensified due to the collection of the gas ***MSW*** landfill.

In my opinion, the above mentioned remarks should be taken into consideration when a CH_4 methane gas emission calculus formula is applied, for the entirely territory of Romania.

4. Example of Calculus, Methodology—The Assessment

Basic consideration:

a) The percentage composition of ***MSW*** landfill body is in accordance with the data provisions given in Table 1.

b) The wastes (rubbish) from the ***MSW*** landfill body are gradually degraded in accordance with the environment conditions;

c) To calculate the quantity of CH_4 gas emission from degraded ***MSW***, at the year of calculation, the

IPCC recommended values [9] have been taken into consideration.

d) The ***MSW*** degraded quantity has the same percentage composition as the ***MSW*** landfill body;

e) The ***MSW*** degraded quantity generates **DOC**-Dissolved Organic Carbon, and, as a consequence, the $\mathbf{CH_4}$ gas emission is produced.

f) The ***MSW*** degraded quantity calculated, in the year ***T***, is given by the expression: $Q_{\text{mswdegrad}.T}$

Within Table 1 the waste composition, as% from total, was established following information delivered by:

• Local Environmental Authorities, in accordance with the Regalement of the Council of Europe no. 2150/2002 and the European Parliament information with referring to the waste statistics (November 25/2002) [17]. For example, for the Region 8 Bucharest Ilfov-landfill Chiajna, the information delivered (see Figure 1, also) are: "Methane Vol.–54.4%, Carbon Dioxide Vol.–38.1%, Oxygen Vol.–1.3%, Nitrogen Vol.–6.1%, etc. As an important remark, within the year 2011 about 7.5 million cubic meters of Methane gas has been extracted."

• Direct observation done at the *MSW* landfills location with referring to the wastes composition;

• Direct information delivered by local authorities regarding annually collected wastes quantities and the way of the management;

• Information delivered by the *MSW* landfills administrators related to the collection area, quantities and type of wastes included in *MSW*.

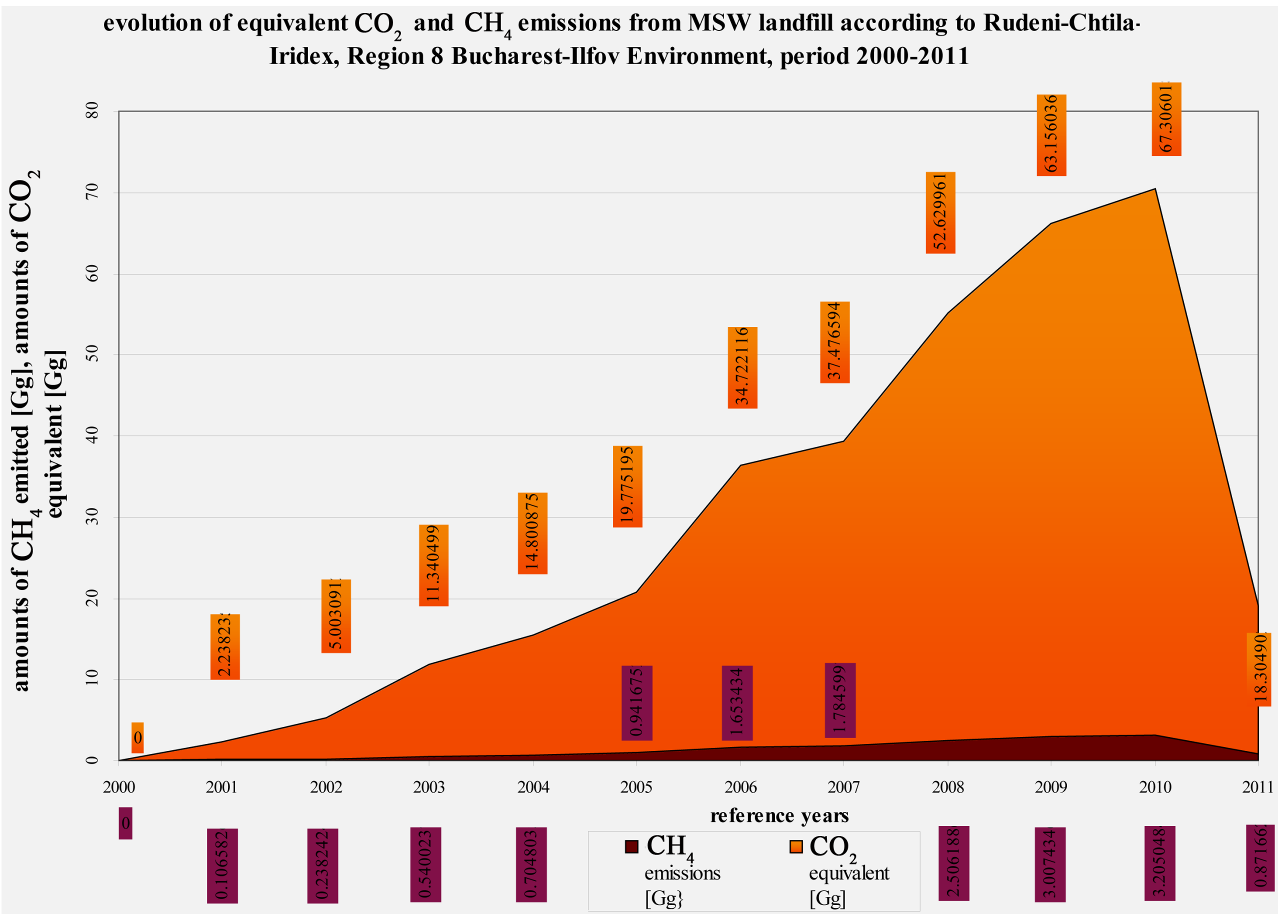

Figure 1. The Evolution of CO_2 (equivalent) and CH_4 emission from the landfill Rudeni-Chitila-Iridex, Environmental Reg. 8, Bucharest, Ilfov District, in the period: 2000 ÷ 2011.

Table 2 presents the composition of the *MSW* landfills wastes, located within 3 environmental regions areas-region 8 Bucharest Ilfov, Satu Mare County and Bihor county. It is to be mentioned that the Waste composition, as a conglomerate landfill, is subjected to the environment factors, and as a consequence, the LFG gas (mainly, CH_4) is generated, covering the total lifetime of the deposit.

5. The Evaluation of $Q_{\text{mswdegrad}.T}$ in the *T* Year of Calculation

To determine the *MSW* degraded quantity, in the first year of emission, the following formula has been used:

$$Q_{msw\text{degrad}.T} = \left[\left(Q_{msw.T} + Q_{msw.T-1}\right)\right] * \left[\left(1 - \exp\left(-Kt\right)\right)\right]\left[Gg\right], \quad (2)$$

After the first year, the calculation formula became:

$$Q_{msw\text{degrad}.T} = \left[\left(Q_{msw.T} + Q_{\text{mswundegra}.T-1}\right)\right] * \left(1 - \exp\left(-Kt\right)\right]\left[Gg\right], \quad (3)$$

where:

- $Q_{msw.T}$-***MSW***, the amount deposited in the account, [Gg];
- $Q_{mswT\text{-}1)}$-***MSW*** deposited one year ago; [Gg];
- $Q_{msw\text{undergradT-1}}$-the remaining amount of ***MSW*** degraded after year calculation [***Gg***];
- ***K***: is the degradation rate of ***MSW***. This factor depends on waste composition and site conditions, and describes the degradation process rate. The IPCC Guidelines [9] give, for *K*, a very wide range of values between 0.005 and 0.4.
- ***t***: time of degradation
- ***t***: time of wastes degradation within deposit body; during calculation process, *t* is replaced with relation (13 − *m*)/12 or (25 − *m*)/12, where m represent the no. of months when msw wastes were degraded within deposit body, at the calculation year. m–within the interval 7 ≤ *m* ≤ 12, *m*- within the interval 7 ≤ *m* ≤ 18, represents no. of months when 45% of the wastes is degraded in the proportion of 45%. The m values are established in accordance with the deposit nomograme, based on the deposit equation $-3x + 7 = 13 - x$, [15]. The deposit

Table 2. The MSW percentage (%) composition within the deposit body in some environmental Romanian regions.

Environmental region	types of wastes					
	Bio from kitchen, cantina's + animal manures, bio-wastes + market wastes + street wastes	Rubbish from gardens and parks	Paper + cartoon non-recyclable + Non recyclable-textiles	Non-recyclables woods and straws	Sludge	Industrial wastes (sisilar to home wastes) + sterilized medical wastes
	All composition% according to the information provided by the Local Environmental Authorities and direct observations from storage place					
Region 8 Environmental Bucharest-Ilfov	51.20	16.00	16.80	3.00	1.00	12.00
Satu Mare county	58.00	13.00	10.30	6.00	1.50	11.20
Bihor county	60.00	11.12	10.88	6.50	2.00	9.50

equation has an unique solution, but in every year has another expression *i.e.* in the year $2-11x+7=25-x$ [15], in the year $3-19x+7=37-x$, [14] etc. How to drawing up the Nomograme [15] of the ***MSW*** deposit will be explained in another paper.

- ***T***-represent the year of calculation not the current calendar year.

A certain ***MSW*** deposited quantity remains undegraded every year [8] [12]. This quantity will be taken into consideration in the next year as the $\boldsymbol{Q}_{\mathbf{mswundegrad.}T}$.

This quantity can be estimated by using the formula:

$$Q_{mswundegrad.T}=\left(Q_{msw.T}+Q_{mswT-1}\right)-Q_{mswdegrad.T}\left[Gg\right], \tag{4}$$

The calculation of the total Dissolved Organic Carbon–(**TDOC**$_{\mathbf{dissolved.}T}$)-quantity from ***MSW*** degraded, at the year *T*, $\boldsymbol{Q}_{\boldsymbol{msw}\mathbf{degrad.}T}$ has been done by means of the following formula

$$\mathrm{TDOC}_{\mathrm{dissolved}.T}=\sum\left[A+B+C+D+E+G\right]\left[Gg\right], \tag{5}$$

where:

A **= DOC generated by** $\boldsymbol{Q}_{\boldsymbol{msw}\mathbf{degrad.}T}$ **which contains%** ***MSW***$_{\mathbf{biodegrad}}$ **stated;**

$$A=Q_{mswdegrad.T}*\%Q_{mswbiodehrad.T}*k_0,\left[Gg\right], \tag{6}$$

k$_0$***:*** **in accordance with [9], DOC generation ratio by%** ***MSW***$_{\mathbf{biodegrad.degrad.}T}$, deposited;

B **= DOC generated by** $\boldsymbol{Q}_{\boldsymbol{msw}(G+P)\mathbf{degrad.}T}$ **which contains %*****MSW***$_{(G+P)}$**, stated;**

$$B=Q_{mswdegrad.T}*\%Q_{msw(G+P)degrad.T}*k_1\left[Gg\right], \tag{7}$$

k$_1$**: in accordance with [9], DOC generated ratio by%** ***MSW***$_{(G+P)\mathbf{degrad.}T}$**, deposited;**

C **= DOC generated by** $\boldsymbol{Q}_{\boldsymbol{msw}\mathbf{degrad.}T}$ **which contains %*****MSW***$_{H+C+\mathbf{text.}}$**, stated;**

$$C=Q_{mswdegrad.T}*\%Q_{msw(H+C+\mathrm{text.})degrad.T}*k_2,\left[Gg\right], \tag{8}$$

k$_2$**: in accordance with [9], DOC generated ratio by %*****MSW***$_{(H+C+\ \mathbf{text.})\mathbf{degrad.}T}$**, deposited;**

D **= DOC generated by** $\boldsymbol{Q}_{\boldsymbol{msw}\mathbf{degrad.}T}$ **which contains %*****MSW***$_{(\mathbf{wood+straw})}$**, stated**

$$D=Q_{mswdegrad.T}*\%MSW_{(\mathrm{wood+straw})degrad.T}*k_3,\left[Gg\right], \tag{9}$$

k$_3$**: in accordance with [9], DOC generated ratio by%** ***MSW***$_{(\mathbf{wood+strawdegrad.})T}$**, deposited;**

E **= DOC generated by** $\boldsymbol{Q}_{\boldsymbol{msw}\ \mathbf{degrade.}T}$ **which contains %*****MSW***$_{\mathbf{sludge}}$**, stated;**

$$E=Q_{mswdegrad.T}*\%MSW_{\mathrm{sludg.degrad.}T}*k_n,\left[Gg\right], \tag{10}$$

k$_n$**: in accordance with [9], DOC generated ratio by%** ***MSW***$_{\mathbf{sludg.degrad.}T}$**, deposited;**

G **= DOC generated by** $\boldsymbol{Q}_{\boldsymbol{msw}\mathbf{degrad.}T}$ **which contains %*****MSW***$_{\mathbf{industry,}}$ **stated;**

$$G=Q_{mswdegrad.T}*\%Q_{mswind.degrad.T}*k_4,\left[Gg\right], \tag{11}$$

k$_4$**: in accordance with [9], DOC generated ratio by%** ***MSW***$_{\mathbf{ind.degrad.}T}$**, deposited.**

The total composition of *MSW* wastes within the body can be changed annually, at two years, at three years or five years depending on the best environment information detained.

% $TDOC_{dissolved.T}$ is the ratio $\left(TDOC_{dissolved.T}\right)/\left(Q_{msw\ \text{taken into consid.}T}\right)$ because **DOC** is distributed within total wastes deposited but it is considered to be generated only by $Q_{msw\text{degrad.}T}$ and it is determined by using the following formula:

$$\%TDOC_{dissolved.T} = \left(TDOC_{dissolved.T}\right)/\left(Q_{msw\ \text{taken into consid.}T}\right)[\%] \tag{12}$$

where $Q_{msw\ \text{taken into consid.}T}$ is calculated by using the relation:

$$Q_{msw\ \text{taken into consid.}T} = Q_{msw.T} + Q_{msw\ \text{undergrad.}T-1}, [Gg] \tag{13}$$

• **DOC_f = fraction [%] of DOC dissolved** under anaerobic conditions (taking into consideration the environmental condition from landfill) which generated CH_4.

The calculus can be done in this way**:**

• Empirical [16] by using the formula**: 0.014 *T* + 0.28,** where ***T***–is the annual average temperature, in C^0, in the district where *MSW* is located.

By using IPCC recommended values for the temperate-continental zones, in Eastern and Central Europe, [5] [9] we found the following percentage values: 50%, 55%, 60% and 77%.

If we take into consideration the Romanian districts climate zone conditions the recommended values (as percentage) are to be: 43%, 45%, 50%, 55% and 60%.

• **1.3333(16/12)** is the conversion factor of the carbon from CH_4 emission.

• ***F***-*MSW* landfill CH_4 gas emission correction factor and depends on the management of landfill; this factor assumes the compacting level of the solid municipal waste (rubbish) *MSW* landfill body and its values are:

a) 0.4 ÷ 0.5-if *MSW* landfill is not compacted*;*

b) 0.6 ÷ 0.7-if the *MSW* landfill is compacted by means of a compactor and a bulldozer;

c) 0.8 ÷ 0.9-if *MSW* landfill is compacted with two bulldozers and two compactors. It is to be observed that there is not value 1 because there are no perfect ways of *MSW* management.

• F_r-is a correction factor of CH_4 gas emission fraction from gas deposit [Landfill Gas- *LFG*], according to the IPPC recommended values; these values of F_r are within interval 40 ÷ 60%,

Taking into consideration the above formula and using adequate input data, the graphical representations for the evolution of the equivalent CO_2 of *MSW* landfills [4] [9] [13]—Landfill Rudeni-Chitila-Iridex, Landfill Vidra-Ecosud are presented in **Figure 1** and **Figure 2**.

The evolution of the equivalent **CO_2** for a non-conforming ***MSW*** landfill is presented in **Figure 3**. It is to be observed that the **CH_4** gas emission continues, after the closing date–the year 2010, as shown.

Wastes deposited quantities (*msw*) within deposit body are shown in **Table 3**. These quantities, due to **"*m*"** values, according to the Nomogrinitial [15], generated CH_4 quantities as presented within **Figure 1**, with the following signi-

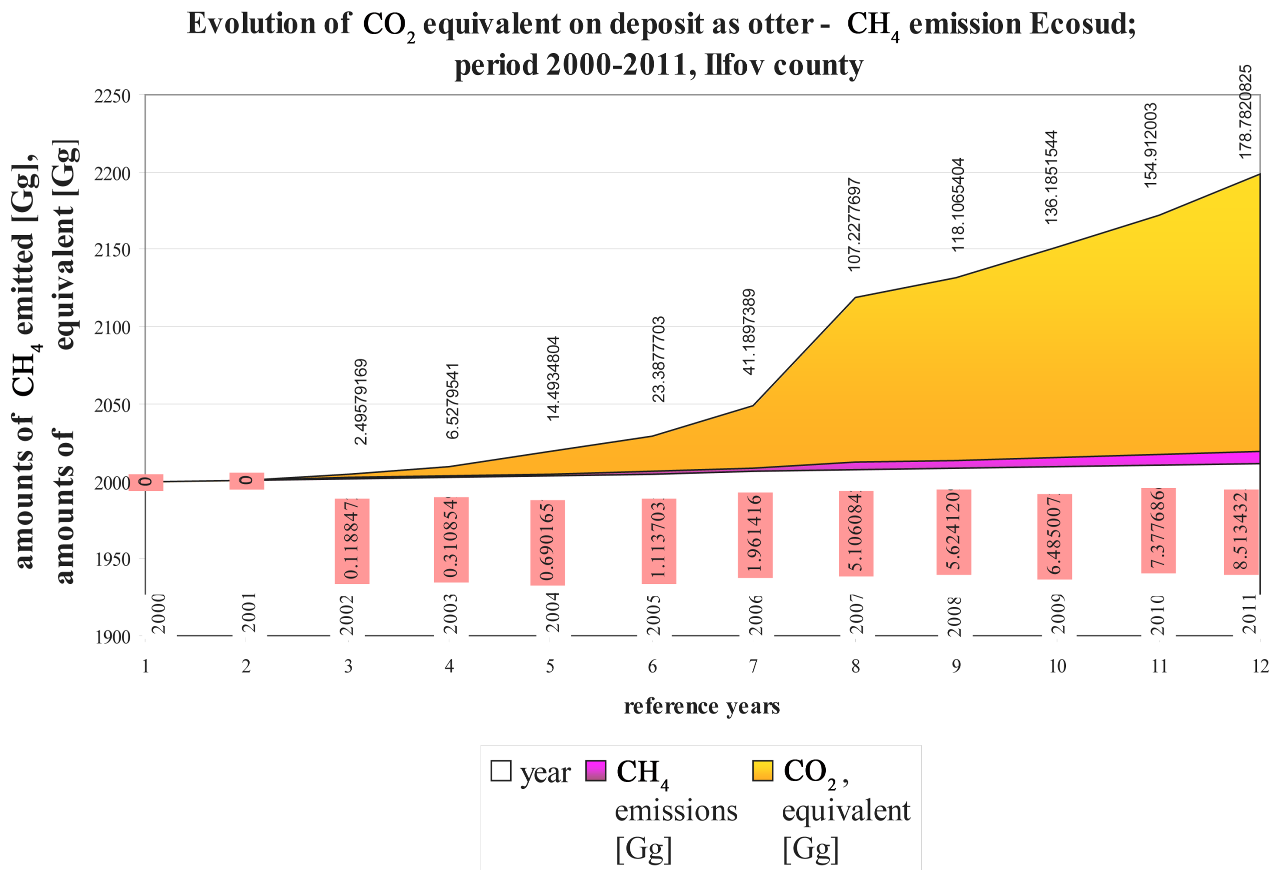

Figure 2. Evolution of CO_2 (equivalent) and CH_4 Methane gas emission from the landfills Vidra-Ecosud, Ilfov District, in the period: 2000 ÷ 2011.

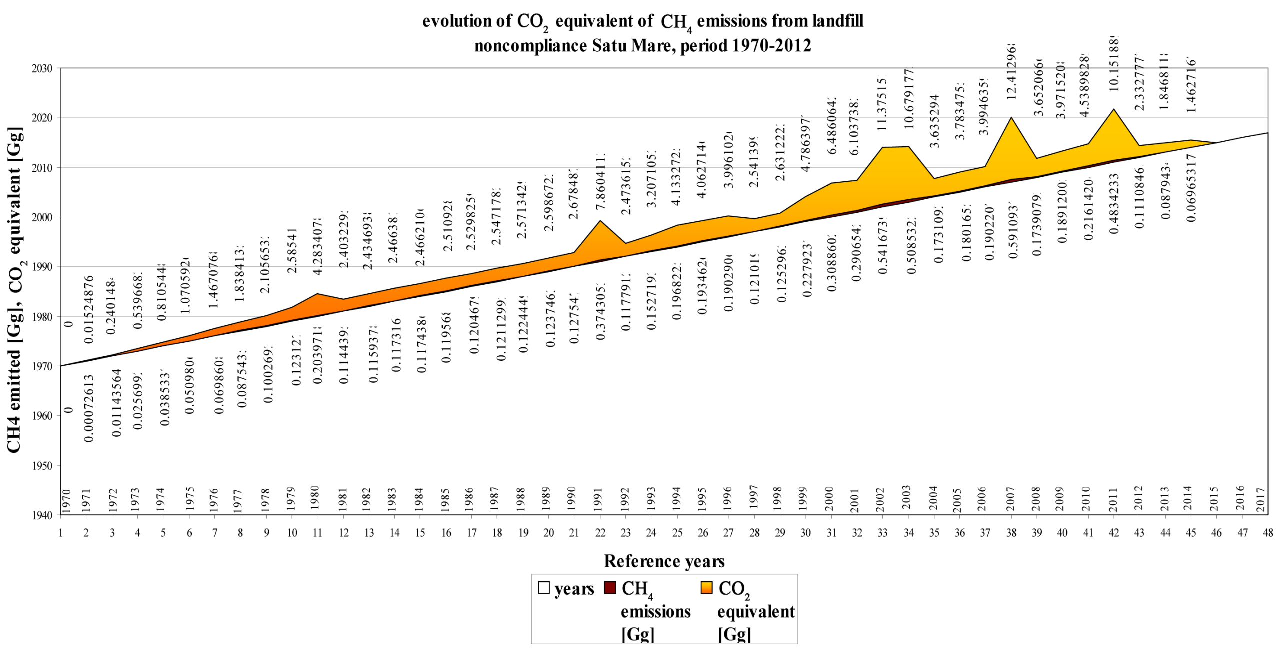

Figure 3. The MSW landfill disposal time period: 1970 ÷ 2015 lasting for CH_4 gas emission, after disposal was completed. The percentage composition of MSW may be changed, year by year. The sludge from MSW can be taken into consideration, separately or may be incorporated within bio-degraded waste (rubbish).

Table 3. Present the *MSW* wastes deposited within the body, for the period 2000 ÷ 2011.

Landfill (*MSW*) Chitila-Iridex, environmental Region 8 Bucharest-Ilfov											
Year of storage											
2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Quantities of wastes (*MSW*) stored [*Gg*]											
43.536	361.15	361.65	309.42	349.46	384.45	367.98	245.49	448.69	434.85	425.52	361.00

ficance [9] [13] [15]: in the year 2011 there were collected 7.5 million cubic meters of CH_4 which have been used for green energy production.

For the period 2000 to 2011, the percentage **(%)** of ***MSW*** composition has been considered, as shown in **Table 1**. Plastic wastes, inert waste, construction and demolition have not to be taken into consideration because they will not affect the $\mathbf{CH_4}$ gas emission [8] [14].

The data were confirmed by collection data.

6. A Case Study

Within 2000 ÷ 2011 period (see **Figure 1**) quantities belonging to the interval 250 ÷ 400 *Gg*, there were deposited, annually. The GEG Effect has been intensified has been intensified, so that in the year of 2011 and a quantity of 7.5 million cubic meters of CH_4 has been used for electric energy production. As a direct consequence the GEG Effect decreased considerably, see **Figure 1**.

For the period 2000 to 2011, the $\mathbf{CH_4}$ calculated values of gas emissions are presented in **Figure 1**, by using Formula (1):

$$\mathrm{CH}_{4(Gg/\mathrm{zear})T} = Q_{msw\mathrm{degrad}.T} * \%\mathrm{TDOC}_{\mathrm{dissolved}.T} * DOC_f * 16/12 * F * F_r, \quad (1)$$

Using some indicators related to the *MSW* landfills $\mathbf{CH_4}$ gas emission, a calculation model is presented below. These indicators are those recommended by IPCC group of experts, group for the Central and Eastern Europe, [9] as follows:

$Q_{msw2000} = 43{,}536\ [Gg]$ *MSW* landfill deposited at the Year 2000;

$Q_{msw2001} = 361{,}157[Gg]$ *MSW* landfill deposited at the Year 2001;

$$Q_{msw\mathrm{degrad}.T} = \left[\left(Q_{msw.T} + Q_{msw.T-1}\right)\right] * \left[\left(1 - \exp(-Kt)\right)\right][Gg], \quad (2)$$

At the starting year of CH_4 emission within the Equation (2) can be used the expression:

$\left[\left(1 - \exp\left(-K\left(13 - m/12\right)\right)\right)\right]$ [3] where m represents the number of months in which maximum **45%** of deposited *MSW* are degradeted, $7 \le m \le 12$ [3].

After the emission starting the expression $\left[\left(1 - \exp\left(-K\left(25 - m\right)/12\right)\right)\right]$, [15], $7 \le m \le 18$ [15] can be used. m-the number of months is allocated to the *MSW* Nomograme [15].

$$Q_{msw\mathrm{degrad}.2001} = \left[\left(Q_{msw2000} + Q_{msw2001}\right)\right] * \left[\left(1 - \exp\left(-K\left(13 - m\right)/12\right)\right)\right], [Gg]$$

$Q_{msw\ \mathrm{degrad}.T}$ is degraded quantity, Equation (2) Which generated **DOC** (Organic Carbon Dissolved), and, finally, $\mathbf{CH_4}$, at the year 2001.

$K = 0,4,\ m = 9,\ 7 \le m \le 12$ [3], no. of months for the period 2000-2001, when MSW are degradeted, according to the MSW landfill Nomograme [15].

$$Q_{msw\text{degrad.2001}} = (43.536 + 361.157) * (1 - 0.8781); [Gg]$$

$$Q_{msw\text{degrad.2001}} = 49,332[Gg], \text{calculated by using the } Eq. \tag{3}$$

By using Equation (4) the $Q_{msw\,\text{undegrad.2001}}$ is calculated.

$$Q_{msw\,\text{undegrad.}T} = (Q_{msw\,T} + Q_{msw\,T-1}) - Q_{msw\,\text{degrad.}T}, [Gg] \tag{4}$$

$Q_{msw\,\text{undegrad.2001}} = (361.157 + 43.536) - 49.332$, [Gg], calculated by using the Equation (4)

$Q_{msw\ \text{undegrad.2001}} = 355.361$ [Gg], $\boldsymbol{MSW}$ quantity remained un-degraded in the end of 2001.

By using formula shown below, the percentage of %TDOC has been determined:

$$\%\text{TDOC}_{\text{dissolved.}T} = (\text{TDOC}_{\text{dissolved.}T}) / (Q_{msw\ \text{taken into consid.}T})[\%] \tag{12}$$

$\text{TDOC}_{\text{dissolced}T}$ – Total Organic Dissolved Carbon (DOC), $[Gg]$ was determined, such as:

$$\text{TDOC}_{\text{dissolved.2001}} = \sum[A + B + C + D + E + G], [Gg], \tag{5}$$

The terms A, B, C, D, E, G are calculated at the year 2001, by using adequate equations

$$A = Q_{msw\text{degrad.}T} * \%Q_{msw\text{biodehrad.}T} * k_0, [Gg], \tag{6}$$

$$A_{2001} = Q_{msw\ \text{degrad.2001}} * \%Q_{msw\ \text{biodegrad.2001}} * k_0, [Gg]$$

$k_0 = 0.185$, the bio-degradable wastes DOC generation ratio, is in accordance with [IPCC, 2006], Chapter V, wastes;

$$Q_{msw\ \text{degrad.2001}} = 49.332[Gg]$$

$$\%MSW_{\text{biodegrad}} = 51.2$$

$$A_{2001} = 49.332 \times 0.512 \times 0.185 = 4.673, [Gg]$$

$$B = Q_{msw\text{degrad.}T} * \%Q_{msw(G+P)\text{degrad.}T} * k1, [Gg], \tag{7}$$

$$B_{2001} = Q_{msw\ \text{degrad.2001}} * \%Q_{msw(G+P)\text{degrad.2001}} * k_1, [Gg]$$

$k_1 = 0.1$, the park and garden wastes **DOC** generation ratio, in accordance with [IPCC, 2006], Chapter V wastes;

$$\%Q_{msw\ G+P} = 16$$

$$B_{2001} = 49.332 * 0.16 * 0.1 = 0.789, [Gg]$$

$$C = Q_{msw\ \text{degrad},T} * \%Q_{msw\ H+C+\text{text.degrad.}T} * k_2, [Gg] \tag{8}$$

$$C_{2001} = Q_{msw\ \text{degrad.2001}} * \%Q_{msw(H+C+\text{text.})\text{degrad.2001}} * k_2, [Gg]$$

$k_2 = 0.06$, the papers + cartoon + textiles wastes DOC generation ratio, in accordance with [IPCC, 2006], Chapter V, wastes;

$$\%Q_{H+C+\text{text.degrad.2001}} = 16.8$$

$$C_{2001} = 49.332 \times 0.168 \times 0.06 = 0.497(Gg)$$

$$D = Q_{msw\ \text{degrad}.T} * \%MSW_{(\text{Wood+straw})\text{degrad}.T} * k_3, [Gg] \quad (9)$$

$$D_{2001} = Q_{msw\ \text{degrad}.2001} * \%MSW_{(\text{wood+straw})\text{degrad}.2001} * k_3, [Gg]$$

$k_3 = 0.03$, the wood + straw wastes DOC generation ratio in accordance with [IPCC, 2006], Chapter *V*, wastes;

$$\%MSW_{\text{wood+straw}.2001} = 3$$

$$D_{2001} = 49.332 * 0.03 * 0.03 = 0.044, [Gg]$$

$$E = Q_{msw\ \text{degrad}.T} * \%MSW_{\text{sludg.degrad}.T} * k_n, [Gg] \quad (10)$$

$$E_{2001} = Q_{msw\text{degrad}.2001} * \%MSW_{\text{sludg}.2001} * k_n, [Gg]$$

$k_n = 0{,}185$, the containing sludge wastes DOC generation ratio in accordance with [IPCC, 2006], Chapter *V*, wastes;

$$\%MSW_{\text{sludg.degrad}.2001} = 1$$

$$E_{2001} = 49.332 * 0.01 * 0.185 = 0.091, [Gg]$$

$$G = Q_{msw\ \text{degrad}.T} * \%Q_{msw\ \text{ind.degrad}.T} * k_4, [Gg] \quad (11)$$

$$G_{2001} = Q_{msw\ \text{degrad}.2001} * \%Q_{msw\ \text{ind.degrad}.2001} * k_4, [Gg]$$

$k_4 = 0.09$, the industrial wastes (similar to home wastes) DOC generation ratio, in accordance with [IPCC, 2006], Chapter *V*, wastes;

$$\%Q_{msw\,\text{ind.degrad}.2001} = 12$$

$$G_{2001} = 49.332 * 0.12 * 0.09 = 0.533, [Gg]$$

$$\text{TDOC}_{\text{dissolved}.T} = \sum [A + B + C + D + E + G], [Gg] \quad (5)$$

$$\text{TDOC}_{\text{dissolved}.T} = 4.673 + 0.789 + 0.497 + 0.044 + 0.094 + 0.533 = 6.133[Gg]$$

$$\%\text{TDOC}_{\text{dissolved}.T} = (\text{TDOC}_{\text{dissolved}.T}) / (Q_{msw\ \text{taken into consid}.T})[\%] \quad (12)$$

$$\%\text{TDOC}_{\text{dissolved}.2001} = (\text{TDOC}_{\text{dissolved}.2001}) / (Q_{msw\ \text{taken into consid}.2001})[\%]$$

$$Q_{msw\ \text{taken in to consid}.T} = Q_{msw\ T} + Q_{msw\ \text{undegrad}.T-1}[Gg] \quad (13)$$

$$Q_{msw\ \text{taken in to consid}.2001} = Q_{msw2001} + Q_{msw\ \text{undegrad}.2001}[Gg]$$

$$Q_{msw\ \text{taken in to consid}.2001} = 361.157 + 43.536 = 404.693, [Gg]$$

$$\%\text{TDOC}_{2001} = 6.133/404.693 = 0.01515;\ 1.52\%\ \text{respectively};$$

The $\mathbf{CH_4}$ gas emission quantity at the year 2001 is calculated by applying the $Eq.(1)$, as follows:

$$\text{CH}_{4\text{emission}/2001} = 49.332 * 0.0152 * 1.3333 * 0.5 * 0.6 * 0.5 = 0.14997[Gg]$$

where:

49.332 [Gg] is *MSW* degraded quantity at the year 2001 which generated DOC and, later on, CH_4 methane gas [5] [7] [10];

- 1.52% is the percentage% TDOC within landfill body;
- 0.5 represent DOC_f taking into consideration the existing condition from the analyzed emission;

- 1.3333 (16/12) represent C from CH_4;
- 0.6 represents the management level of the analyzed MSW landfill, at the year 2001;
- 0.5 represents the% content of CH_4 Methane gas within Landfill Gas (LFG).

It is to be observed that the CH_4 gas emission increased gradually, but not suddenly, in accordance with the environmental condition of the landfill location [6]. A certain wastes (rubbish) quantity of MSW landfill will remain un-degraded and will be taken into consideration in the next year, so the process of MSW degraded will generate again DOC, and, as a consequence, CH_4 Methane gas:

$$CO_{2\text{equivalent}2001} = CH_{4\text{emitted}2001} * 21 = 0.14997 = 3.14937[Gg]$$

At the year 2011, for the same MSW landfill-Chitila-Rudeni-Iridex, the quantity of CH_4 emission will be [8] [12] [15];

$Q_{msw2011} = 361.000[Gg]$ MSW, deposited

$Q_{msw\text{undegrad}.2010} = 496.989[Gg]$, the quantity of MSW landfill un-degraded, remained from the year 2010;

$$Q_{msw\text{ taken in to consid}.T} = Q_{msw\ T} + Q_{msw\text{ undegrad}.T-1}[Gg] \quad (13)$$

$$Q_{msw\text{ taken into consid}.2011} = 361.000 + 496.989 = 857.989,[Gg]$$

MSW landfill deposited taken into consideration for the calculus of $Q_{msw\text{ degrad}.2011}$:

By using the Formula (2)

$$Q_{msw\text{degrad}.T} = \left[\left(Q_{msw.T} + Q_{msw\text{undegrad}.T-1}\right)\right] * \left[\left(1 - \exp(-Kt)\right)\right][Gg], \quad (3)$$

$K = 0,4;\ m = 7$ in accordance with MSW deposit nomograme [3] [13] [17].

$$Q_{msw\text{ degrad}.2011} = 387.125[Gg]$$

the non-degraded quantity of MSW remained in the end of the year 2011; the $Eq.(4)$ is used:

$$Q_{msw\text{undegrad}.T} = \left(Q_{mswT} + Q_{msw\text{undegrad}.T-1}\right) - Q_{msw\text{ degrad}.T},[Gg] \quad (4)$$

$$Q_{msw\text{undegra}.2011} = 857.989 - 387.125 = 470.864,[Gg]$$

By using the Equation (12), the percentage $\%TDOC_{\text{dissolved}.T}$ has been calculated, as follows:

$$\%TDOC_{\text{dissolved}.T} = \left(TDOC_{\text{dissolved}.T}\right) / \left(Q_{msw\text{ taken into consid}.T}\right)[\%] \quad (12)$$

$TDOC_{\text{dissolved}2011},[Gg]$ was calculated by using the Equation (5)

$$TDOC_{\text{dissolved}.T} = \sum[A + B + C + D + E + G],[Gg] \quad (5)$$

The parameters-A, B, C, D, E, F, G, are determined at the year 2011, by using corresponding equations.

$$A = Q_{msw\text{ degrad}.T} * \%Q_{msw\text{ biodegrad}.T} * k_0,[Gg] \quad (6)$$

$$A_{2011} = Q_{msw\text{ degrad}.2011} * \%Q_{msw\text{ biodegrad}.2011} * k_0,[Gg]$$

$k_0 = 0.185$ the biodegradable DOC generation ratio, in accordance with [IPCC, 2006], Chapter V, wastes.

$$Q_{msw\ \text{degrad}.2011} = 387.879[Gg]$$

$$\%MSW_{\text{biodegrad}} = 51.2$$

$$A_{2011} = 387.125 * 0.512 * 0.185 = 36.685,[Gg]$$

$$B = Q_{msw\ \text{degrad}.T} * \%Q_{msw(G+P)\text{deg}rad.T} * k_1,[Gg] \quad (7)$$

$$B_{2011} = Q_{msw\text{degrad}.2011} * \%Q_{msw(G+P)\text{degrad}.2011} * k_1,[Gg]$$

$k_1 = 0.1$, parks and garden wastes **DOC** generation ratio in accordance with [IPCC, 2006], Chapter V, wastes [7] [9] [10].

$$\%Q_{msw(G+P)} = 16$$

$$B_{2011} = 387.125 * 0.16 * 0.1 = 6.194[Gg]$$

$$C = Q_{msw\ \text{degrad},T} * \%Q_{msw(H+C+\text{text}).\text{degrad}.T} * k_2,[Gg] \quad (8)$$

$$C_{2011} = Q_{msw\ \text{degrad}.2011} * \%Q_{msw(H+C+\text{text}.)\text{degrad}.2011} * k_2,[Gg]$$

$k_2 = 0.06$, the papers + cartoon + textiles wastes DOC generation ratio in accordance with [IPCC, 2006], Chapter V, wastes.

$$\%Q_{(H+C+\text{text}.)\text{degrad}.2001} = 16.8$$

$$C_{2011} = 387.125 * 0.168 * 0.06 = 3.902[Gg]$$

$$D = Q_{msw\ \text{degrad}.T} * \%MSW_{(\text{Wood+straw})\text{degrad}.T} * k_3,[Gg] \quad (9)$$

$$D_{2011} = Q_{msw\ \text{degrad}.2011} * \%MSW_{(\text{wood+straw})\text{degrad}.2011} * k_3,[Gg]$$

$k_3 = 0.03$, the wood + straw wastes DOC generation ratio in accordance with [IPCC, 2006], Chapter V, wastes.

$$\%MSW_{\text{wood+straw}.2001} = 3$$

$$D_{2011} = 387.125 * 0.03 * 0.03 = 0.384[Gg]$$

$$E = Q_{msw\ \text{degrad}.T} \times \%MSW_{\text{sludg.degrad}.T} \times k_n,[Gg] \quad (10)$$

$$E_{2011} = Q_{msw\text{degrad}.2011} * \%MSW_{\text{sludg}.2001} * k_n,[Gg]$$

$k_n = 0.185$, wastes (containing sludge) **DOC** generation ratio in accordance with [IPCC, 2006], Chapter V, wastes [9] [10] [17].

$$\%MSW_{\text{sludg.degrad}.2001} = 1$$

$$E_{2011} = 387.125 * 0.01 * 0.185 = 0,716,[Gg]$$

$$G = Q_{msw\ \text{degrad}.T} * \%Q_{msw\ \text{ind.degrad}.T} * k_4,[Gg] \quad (11)$$

$$G_{2011} = Q_{msw\ \text{degrad}.2011} * \%Q_{msw\ \text{ind.degrad}.2011} * k_4,[Gg]$$

$k_4 = 0.09$, MSW landfill containing industrial wastes (similar to home wastes) DOC generation ratio, in accordance with [IPCC, 2006], Chapter V wastes,

$$\%Q_{msw\,\text{ind.degrad}.2011} = 12$$

$$G_{2011} = 387.125 * 0.12 * 0.09 = 4.181, [Gg]$$

$$\text{TDOC}_{\text{dissolved}.T} = \sum [A + B + C + D + E + G], [Gg] \quad (5)$$

$$\text{TDOC}_{\text{dissolved}.2011} = 36.685 + 6.194 + 3.902 + 0.384 + 0.716 + 4.181 = 52.062, [Gg]$$

$$\%\text{TDOC}_{\text{dissolved}.T} = (\text{TDOC}_{\text{dissolved}.T}) / (Q_{msw\text{ taken into consid}.T}) [\%] \quad (12)$$

$$\%\text{TDOC}_{\text{dissolved}.2011} = (\text{TDOC}_{\text{dissolved}.2011}) / (Q_{msw\text{ taken into consid}.2011}) [\%]$$

$$Q_{msw\text{ taken in to consid}.T} = Q_{msw\ T} + Q_{msw\text{ undegrad}.T-1}, [Gg] \quad (13)$$

$$Q_{msw\text{ taken in to consid}.2011} = Q_{msw2011} + Q_{msw\text{ undegrad}.2010} [Gg]$$

$$Q_{msw\text{ taken in to consid}.2011} = 361.000 + 496.989 = 857.989 [Gg]$$

$$\%\text{TDOC}_{2001} = 52.062/857.989 \quad 0.0607; \quad 6.07\%\text{, respectively.}$$

The quantity of $\mathbf{CH_4}$ in the year 2011 gas emission is calculated by applying Formula (1) as follows:

$$\text{CH}_{4\text{emission}/2011} = 387.125 * 0.0607 * 1.3333 * 0.5 * 0.9 * 0.5 = 7.0494, [Gg]$$

where:

- 387.125 [Gg] is *MSW* degraded quantity of in 2011 which generated **DOC** and, later on, $\mathbf{CH_4}$
- Methane gas; 6.07% , is the percentage % **TDOC** within landfill body;
- 0.5 represent $\mathbf{DOC}_f$ taking into consideration existing condition from the analyzed emission;
- 1.3333 (16/12) represent C from $\mathbf{CH_4}$;
- 0.9 represents the management level of the analyzed *MSW* landfill, in the year 2001;
- 0.5 The content $[\%]$ of $\mathbf{CH_4}$ methane gas within Landfill Gas **(LFG).**

It is to be observed that the $\mathbf{CH_4}$ gas emission increased gradually, but not suddenly, in accordance with the environmental condition of the landfill location [6]. A certain waste (rubbish) quantity of ***MSW*** landfill will remain un-degraded and will be taken into consideration in the next year, so the process of *MSW* degraded will generate again **DOC**, and, as a consequence, $\mathbf{CH_4}$ Methane gas:

$$\text{CO}_{2\text{equivalent}2011} = \text{CH}_{4\text{emitted}2011} * 21 = 148.037 [Gg]$$

It is to be observed that the $\mathbf{CH_4}$ gas emission increased gradually, but not suddenly, in accordance with the environmental condition of the landfill location [4] [6]. A certain waste (rubbish) quantity of ***MSW*** landfill will remain un-degraded and will be taken into consideration in the next year, so the process of ***MSW*** degraded will generate again **DOC**.

The sludge from *MSW* can be taken into consideration, separately or may be incorporated within bio-degraded waste (rubbish).

7. Conclusions

This article doesn't comment on the present calculation model but rather draws the attention to a more adapted to the real conditions estimation, by calculus, of the $\mathbf{CH_4}$ gas emission from the actual ***MSW*** landfills in Romania, which have to be estimated by the end of 2017. Even if deposited ***MSW*** quantities were up to 30 (Gg), in the beginning of 1979 and reached 90 (Gg) in 2010, the evolution of $\mathbf{CO_2}$ exists and has to be known by the Romanian authorities.

It is considered that this estimation has to be determined up to the life-end of the considered landfill. As an example, at the existing ***MSW*** landfill, in the Satu Mare County, the evolution of the equivalent $\mathbf{CO_2}$ for a period of 42 years up to 2010 when it was closed is presented. The authorities have to inform the public about the evolution of the equivalent $\mathbf{CO_2}$ for existing ***MSW*** landfill and also for the location of the new ***MSW*** landfills.

On the other hand, for the non-hazardous ***MSW*** landfills having a capacity between $350 \div 450$ [Gg] it was observed that the top management of this ***MSW*** landfills issued estimated quantities of $\mathbf{CH_4}$ gas at unrealistic values, sometimes more than two times lower with respect to the real one, estimated by usual calculation models.

To reduce the greenhouse effect, the evolution of the equivalent $\mathbf{CO_2}$ for the existing ***MSW*** landfills in Romania has to be estimated in such a way as to be useful for an applicable environmental planning in accordance with the government's and the European policy in the field of environmental protection. Other gas emissions such as: NON-METHANE ORGANIC **COMPOUNDS**, NO_2, NO_x, Polycyclic aromatic hydrocarbons, HFC, PFC have not been taken into consideration.

The real estimation of the $\mathbf{CH_4}$ emission quantity from ***MSW*** landfills, in Romania, will contribute to a better environmental planning and a better understanding of the contribution that different gases have on the general warming effect and climate changes greenhouse effect.

Finally, it is to be noted that the calculation of the CH_4 emission quantity, by using the **Danila Vieru's Method**, (**Formula**1), will help Romanian environmental authorities to implement the legal and right decisions regarding the adequate moment when the collected CH_4 emission can be burned, and thus be used in an economical manner.

The proposed method could be applied for the $\mathbf{CH_4}$ emission calculation at ***MSW*** landfills quantities between 100 ÷ 200 (Gg/y) e.g. the Satu Mare non-conforming *MSW* landfill (see Figure 3).

This method which was verified for Romanian landfills could be easily adapted for other countries too, paving the way for a real estimation of the methane gas emission, as real as possible.

The proposed method can be applied either to the *MSW* landfills which respect legal providing and those (*MSW*) which not respect such provisions. The quantitative CH_4 estimation is beneficial for the Environmental Authorities but also for the potential investors interested in the CH_4 management. It is to be noted that potential investors have to know the emission quantity and its duration. After *MSW* depositing is over, it is absolutely necessary to the time-duration when the emission is stopped. In the same time, after the CH_4 emission is over, the resulted compost should be of interest for the farmers.

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