A New Approach Method of CH₄ Emission Estimation from Landfills Municipal Solid Waste (MSW)

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Abstract

The CH₄ 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 CH₄ 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 CH₄ gas emission, in order to apply an efficient management of the CH₄ 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 CH₄ gas emission from all MSW deposits in Romania. The IPCC group of experts has made recommendations related to the estimation of CH₄ but the European Union (EU) admits that the environmental conditions are not the same in every Member State. The annual evolution of CO₂ for the CH₄ 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 $CH_4$ 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 gener-
ated 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 CH₄ 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 CH₄ and, in the next year, it will be a new amount of CH₄. 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 CH₄ and CO₂ 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 CH₄ emission [10] [11] will be indicated, as follows.

These calculus equations are:

| Description of the composition of MSW landfills | Percentage [%] |
|-----------------------------------------------|----------------|
| Bio from kitchen, cantina’s + animal manures,  | 51.2 + 60      |
| bio-wastes + market wastes + street wastes    |                |
| 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) +  | 12 + 6.4       |
| sterilized medical wastes                     |                |

Table 1. The percentage (%) composition of the MSW landfills.
\[ \text{CH}_4(\text{Gg/year}) = \left[ (MSW_f \cdot MSW_{f,S} \cdot L_0) - R \right] \cdot (1 - 0.1X) \]

where:
- \( L_0 \)-CH\(_4\) generated potential \((G_gC/gMSW)\) 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 \((G_gC/gMSW)\), 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.

\[ L_{0GgC/ggMSW} = [MCF \cdot DOC_f \cdot F \cdot 6/12] \]

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:

\[ \text{DOC}_{(G_gC/ggMSW)} = \left( 0.4 \cdot A \right) + \left( 0.17 \cdot B \right) + \left( 0.15 \cdot C \right) + \left( 0.3 \cdot D \right) \]

where:
- \( A \)-the MSW fraction represented by paper and non-reciclabale 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 conglomater 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 CH₄ 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 CH₄ 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 CH₄ gas emission from MSW landfills but not 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 CH₄ 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 CH₄ GAS EMISSION ESTIMATION IN ROMANIA, BY CALCULUS”

The method: “Danila Vieru method for conforming and non-conforming MSW landfills CH₄ gas emission estimation, in Romania, by calculus”, makes use of the following formula:

\[ CH_4 (Gg/year)_r = Q_{mswdegrad,T} * \% TDOC_{dissolved,T} * DOC_f * 16/12 * F * F_r, \]  

(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\textsubscript{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\textsubscript{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\textsubscript{4} gas emission is imperative. In the meantime, measures to reduce the contribution of the CH\textsubscript{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\textsubscript{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\textsubscript{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\textsubscript{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\textsubscript{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\textsubscript{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 **CH₄** gas emission is produced.

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

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](image-url). The Evolution of CO₂ (equivalent) and CH₄ 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, CH₄) 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:

\[
Q_{\text{mswdegrad}.T} = \left[ (Q_{\text{msw}.T} + Q_{\text{msw}.T-1}) \right] \ast \left[ 1 - \exp(-Kt) \right] \ast Gg, \tag{2}
\]

After the first year, the calculation formula became:

\[
Q_{\text{mswdegrad}.T} = \left[ (Q_{\text{msw}.T} + Q_{\text{mswdegrad}.T-1}) \right] \ast \left[ 1 - \exp(-Kt) \right] \ast Gg, \tag{3}
\]

where:

- \( Q_{\text{msw}.T} \) - MSW deposited in the account, [Gg];
- \( Q_{\text{msw}.T-1} \) - MSW deposited one year ago; [Gg];
- \( Q_{\text{mswdegrad}.T-1} \) - 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 \( 7 \leq m \leq 12 \), \( m \)-within the interval \( 7 \leq m \leq 18 \), 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 nomogram, based on the deposit equation \( 3x + 7 = 13 - x \), [15]. The deposit
equation has a 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 Nomogram [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 \( Q_{\text{msw und}} \).

This quantity can be estimated by using the formula:

\[
Q_{\text{msw und}}(T) = (Q_{\text{min T}} + Q_{\text{min T-1}}) - Q_{\text{mswgrad T}}[Gg],
\]

(4)

The calculation of the total Dissolved Organic Carbon-(DOC dissolved. \( T \)) quantity from MSW degraded, at the year \( T \), \( Q_{\text{mswgrad T}} \) has been done by means of the following formula

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

(5)

where:

\( A \): DOC generated by \( Q_{\text{msw biodegrad T}} \) which contains % MSW biodegrad. stated;

\[
A = Q_{\text{msw biodegrad T}} \times \%Q_{\text{msw biodegrad T}} \times k_0 [Gg],
\]

(6)

\( k_0 \): in accordance with [9], DOC generation ratio by % MSW biodegrad. deposited;

\( B \): DOC generated by \( Q_{\text{msw(Gr.+P) degrad T}} \) which contains %MSW(Gr.+P) stated;

\[
B = Q_{\text{msw degrad T}} \times \%Q_{\text{msw degrad T}} \times k_1 [Gg],
\]

(7)

\( k_1 \): in accordance with [9], DOC generation ratio by % MSW(Gr.+P) deposited;

\( C \): DOC generated by \( Q_{\text{msw(H+C+text) T}} \) which contains %MSW(H+C+text) stated;

\[
C = Q_{\text{msw degrad T}} \times \%Q_{\text{msw degrad T}} \times k_2 [Gg],
\]

(8)

\( k_2 \): in accordance with [9], DOC generation ratio by % MSW(H+C+text) deposited;

\( D \): DOC generated by \( Q_{\text{msw(wood+straw) T}} \) which contains %MSW(wood+straw) stated;

\[
D = Q_{\text{msw degrad T}} \times \%Q_{\text{msw degrad T}} \times k_3 [Gg],
\]

(9)

\( k_3 \): in accordance with [9], DOC generation ratio by % MSW(wood+straw) deposited;

\( E \): DOC generated by \( Q_{\text{msw sludge T}} \) which contains %MSW sludge stated;

\[
E = Q_{\text{msw sludge degrad T}} \times \%Q_{\text{msw sludge degrad T}} \times k_6 [Gg],
\]

(10)

\( k_6 \): in accordance with [9], DOC generation ratio by % MSW sludge deposited;

\( G \): DOC generated by \( Q_{\text{msw industry T}} \) which contains %MSW industry stated;

\[
G = Q_{\text{msw degrad T}} \times \%Q_{\text{msw degrad T}} \times k_4 [Gg],
\]

(11)

\( k_4 \): in accordance with [9], DOC generation ratio by % MSW industry 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.

\[ \% \text{TDOC}_{\text{dissolved},T} = \frac{(\text{TDOC}_{\text{dissolved},T})}{(Q_{\text{msw taken into consid},T})} \]  

because DOC is distributed within total wastes deposited but it is considered to be generated only by \( Q_{\text{msw taken into consid},T} \) and it is determined by using the following formula:

\[ \% \text{TDOC}_{\text{dissolved},T} = \frac{(\text{TDOC}_{\text{dissolved},T})}{(Q_{\text{msw taken into consid},T})} \times 100 \]  

(12)

where \( Q_{\text{msw taken into consid},T} \) is calculated by using the relation:

\[ Q_{\text{msw taken into consid},T} = Q_{\text{msw},T} + Q_{\text{msw undergrad},T-1} \times [Gg] \]  

(13)

- \( \text{DOC}_f \) = fraction [%] of DOC dissolved under anaerobic conditions (taking into consideration the environmental condition from landfill) which generated \( \text{CH}_4 \).

The calculus can be done in this way:

- Empirical [16] by using the formula: \( 0.014 \times T + 0.28 \), where \( T \)–is the annual average temperature, in \( ^\circ \text{C} \), 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 \( \text{CH}_4 \) emission.

- \( F_{\text{MSW}} \) landfill \( \text{CH}_4 \) 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.

- \( F_e \) is a correction factor of \( \text{CH}_4 \) gas emission fraction from gas deposit [Landfill Gas- LFG ], according to the IPPC recommended values; these values of \( F_e \) 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 \( \text{CO}_2 \) 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 \( \text{CO}_2 \) for a non-conforming MSW landfill is presented in Figure 3. It is to be observed that the \( \text{CH}_4 \) 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 Nomogramme [15], generated \( \text{CH}_4 \) quantities as presented within Figure 1, with the following signi-
Figure 2. Evolution of CO₂ (equivalent) and CH₄ 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 CH₄ 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.

| 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 CH₄ 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 CH₄ 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 and has been intensified, so that in the year of 2011 and a quantity of 7.5 million cubic meters of CH₄ 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 CH₄ calculated values of gas emissions are presented in Figure 1, by using Formula (1):

\[
CH_4(Gg/yea) = Q_{mswdegrad.T} \times \%TDOC_{dissolved.T} \times DOC_f \times 16/12 \times F \times F_r, \quad (1)
\]

Using some indicators related to the MSW landfills CH₄ 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:

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

\[
Q_{msw2001} = 361,157 \text{ [Gg] } \quad \text{MSW landfill deposited at the Year 2001;}
\]

\[
Q_{mswdegrad.T} = [(Q_{msw.T} + Q_{msw.T-1}) \times [(1 - \exp(-Km))] [Gg], \quad (2)
\]

At the starting year of CH₄ emission within the Equation (2) can be used the expression:

\[
[(1 - \exp(-K(13 - m/12))) \quad (3)
\]

where \( m \) represents the number of months in which maximum 45% of deposited MSW are degraded, \( 7 \leq m \leq 12 \) [3].

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

\[
Q_{mswdegrad.2001} = [(Q_{msw2000} + Q_{msw2001}) \times [(1 - \exp(-K(13 - m)/12))] [Gg]
\]

\( Q_{msw degrad.T} \) is degraded quantity, Equation (2) Which generated DOC (Organic Carbon Dissolved), and, finally, \( CH_4 \), at the year 2001.
\[ K = 0.4, \ m = 9, \ 7 \leq m \leq 12 \quad [3], \ \text{no. of months for the period 2000-2001, when MSW are degraded}, \ \text{according to the MSW landfill Nomogramme [15]}. \]

\[ Q_{\text{msw\ degrad.2001}} \ = \ (43.536 + 361.157) \times (1 - 0.8781); [Gg] \]
\[ Q_{\text{msw\ degrad.2001}} = 49.332 [Gg], \text{calculated by using the Eq. (3)}\]

By using Equation (4) the \( Q_{\text{msw\ undegrad.2001}} \) is calculated.
\[ Q_{\text{msw\ undegrad.2001}} = (Q_{\text{msw\ T}} + Q_{\text{msw\ T-1}}) - Q_{\text{msw\ degrad.2001}} [Gg] \]
\[ Q_{\text{msw\ undegrad.2001}} = (361.157 + 43.536) - 49.332, [Gg], \text{calculated by using the Equation (4)}\]
\[ Q_{\text{msw\ undegrad.2001}} = 355.361 [Gg], \text{MSW quantity remained un-degraded in the end of 2001}. \]

By using formula shown below, the percentage of \%TDOC has been determined:
\[ \%\text{TDOC}_{\text{dissolved.T}} \ = \ (\text{TDOC}_{\text{dissolved.T}})/(Q_{\text{msw\ taken\ into\ consid.\ T}})[\%] \]

\( \text{TDOC}_{\text{dissolved.T}} \) – Total Organic Dissolved Carbon (DOC), [Gg] was determined, such as:
\[ \text{TDOC}_{\text{dissolved.2001}} = \sum [A + B + C + D + E + G], [Gg]. \]

The terms \( A, B, C, D, E, G \) are calculated at the year 2001, by using adequate equations
\[ A = Q_{\text{msw\ degrad.2001}} \times \%Q_{\text{msw\ biodegrad.2001}} \times k_{01} [Gg], \]
\[ A_{2001} = Q_{\text{msw\ degrad.2001}} \times \%Q_{\text{msw\ biodegrad.2001}} \times k_{01} [Gg] \]
\[ k_{01} = 0.185, \text{the bio-degradable wastes DOC generation ratio, is in accordance with [IPCC, 2006], Chapter V, wastes}; \]
\[ Q_{\text{msw\ degrad.2001}} = 49.332 [Gg] \]
\[ \%\text{MSW}_{\text{biodegrad}} = 51.2 \]
\[ A_{2001} = 49.332 \times 0.512 \times 0.185 = 4.673, [Gg] \]
\[ B = Q_{\text{msw\ degrad.2001}} \times \%Q_{\text{msw\ (G + P)degrad.2001}} \times k_{11} [Gg], \]
\[ B_{2001} = Q_{\text{msw\ degrad.2001}} \times \%Q_{\text{msw\ (G + P)degrad.2001}} \times k_{11} [Gg] \]
\[ k_{11} = 0.1, \text{the park and garden wastes DOC generation ratio, in accordance with [IPCC, 2006], Chapter V, wastes}; \]
\[ \%Q_{\text{msw\ G + P}} = 16 \]
\[ B_{2001} = 49.332 \times 0.16 \times 0.1 = 0.789, [Gg] \]
\[ C = Q_{\text{msw\ degrad.2001}} \times \%Q_{\text{msw\ H + C + text. degrad.2001}} \times k_{21} [Gg], \]
\[ C_{2001} = Q_{\text{msw\ degrad.2001}} \times \%Q_{\text{msw\ H + C + text. degrad.2001}} \times k_{21} [Gg] \]
\[ k_{21} = 0.06, \text{the papers + cartoon + textiles wastes DOC generation ratio, in accordance with [IPCC, 2006], Chapter V, wastes}; \]
\[ \%Q_{\text{H + C + text. degrad.2001}} = 16.8 \]

\[ \]
\[ C_{2001} = 49.332 \times 0.168 \times 0.06 = 0.497 \text{ (Gg)} \]
\[ D = Q_{\text{MSW degraded.2001}} \times % MSW_{\text{Wood+straw degraded.2001}} \times k_3 \text{ (Gg)} \]
\[ D_{2001} = Q_{\text{MSW degraded.2001}} \times % MSW_{\text{Wood+straw degraded.2001}} \times k_3 \text{ (Gg)} \]

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

\[ % MSW_{\text{Wood+straw degraded.2001}} = 3 \]
\[ D_{2001} = 49.332 \times 0.03 \times 0.03 = 0.044 \text{ (Gg)} \]
\[ E = Q_{\text{MSW degraded.2001}} \times % MSW_{\text{sludge degraded.2001}} \times k_4 \text{ (Gg)} \]
\[ E_{2001} = Q_{\text{MSW degraded.2001}} \times % MSW_{\text{sludge degraded.2001}} \times k_4 \text{ (Gg)} \]

\[ k_4 = 0.185 \], the containing sludge wastes DOC generation ratio in accordance with [IPCC, 2006], Chapter V, wastes;

\[ % MSW_{\text{sludge degraded.2001}} = 1 \]
\[ E_{2001} = 49.332 \times 0.01 \times 0.185 = 0.091 \text{ (Gg)} \]
\[ G = Q_{\text{MSW degraded.2001}} \times % MSW_{\text{ind degraded.2001}} \times k_5 \text{ (Gg)} \]
\[ G_{2001} = Q_{\text{MSW degraded.2001}} \times % MSW_{\text{ind degraded.2001}} \times k_5 \text{ (Gg)} \]

\[ k_5 = 0.09 \], the industrial wastes (similar to home wastes) DOC generation ratio, in accordance with [IPCC, 2006], Chapter V, wastes;

\[ % MSW_{\text{ind degraded.2001}} = 12 \]
\[ G_{2001} = 49.332 \times 0.12 \times 0.09 = 0.533 \text{ (Gg)} \]

\[ \text{TDOC}_{\text{dissolved.2001}} = \sum [A + B + C + D + E + G], \text{ (Gg)} \]
\[ \text{TDOC}_{\text{dissolved.2001}} = 4.673 + 0.789 + 0.497 + 0.044 + 0.094 + 0.533 = 6.133 \text{ (Gg)} \]

\[ % \text{TDOC}_{\text{dissolved.2001}} = \left( \frac{\text{TDOC}_{\text{dissolved.2001}}}{\text{Q}_\text{M}_\text{S}W \text{ taken into consid.2001}} \right) \% \]
\[ % \text{TDOC}_{\text{dissolved.2001}} = \left( \frac{\text{TDOC}_{\text{dissolved.2001}}}{\text{Q}_\text{M}_\text{S}W \text{ taken into consid.2001}} \right) \% \]
\[ Q_{\text{M}_\text{S}W \text{ taken into consid.2001}} = Q_{\text{M}_\text{S}W \text{ taken into consid.2001}} + Q_{\text{M}_\text{S}W \text{ taken into consid.2001}} \]
\[ Q_{\text{M}_\text{S}W \text{ taken into consid.2001}} = 361.157 + 43.536 = 404.693 \text{ (Gg)} \]
\[ % \text{TDOC}_{\text{2001}} = 6.133/404.693 \times 0.01515; \ 1.52\% \text{ respectively}; \]

The \( \text{CH}_4 \) gas emission quantity at the year 2001 is calculated by applying the \( Eq. \ (1) \), as follows:

\[ \text{CH}_4 \text{ emission(2001)} = 49.332 \times 0.0152 \times 1.3333 \times 0.5 \times 0.6 \times 0.5 = 0.14997 \text{ (Gg)} \]

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 \(_T\) taking into consideration the existing condition from the analyzed emission;
• 1.3333 (16/12) represent C from CH₄;
• 0.6 represents the management level of the analyzed MSW landfill, at the year 2001;
• 0.5 represents the% content of CH₄ Methane gas within Landfill Gas (LFG).

It is to be observed that the CH₄ 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, CH₄ Methane gas:

\[
\text{CO}_2\text{equivalent}_{2001} = \text{CH}_4\text{emitted}_{2001} \times 21 = 0.14997 = 3.14937 \text{[Gg]}
\]

At the year 2011, for the same MSW landfill-Chitila-Rudeni-Iridex, the quantity of CH₄ emission will be [8] [12] [15];
\[
Q_{\text{msw}2011} = 361.000 \text{[Gg]} \quad MSW\text{, deposited}
\]
\[
Q_{\text{mswundegrad}2010} = 496.989 \text{[Gg]}, \quad \text{the quantity of MSW landfill un-degraded, remained from the year 2010;}
\]
\[
Q_{\text{new taken in to consid.}T} = Q_{\text{new } T} + Q_{\text{new undegrad. } T-1} \text{[Gg]}
\]
\[
Q_{\text{new taken into consid.2011}} = 361.000 + 496.989 = 857.989, \text{[Gg]}
\]

MSW landfill deposited taken into consideration for the calculus of
\[
Q_{\text{new degrad.2011}}:
\]

By using the Formula (2)

\[
Q_{\text{mswundegrad} T} = [(Q_{\text{msw } T} + Q_{\text{mswundegrad } T-1})] \times [(1 - \exp(-Kt))] \text{[Gg]}, \quad (3)
\]

\[
K = 0, 4; \ m = 7 \quad \text{in accordance with MSW deposit nomogram} \ [3] \ [13] \ [17].
\]
\[
Q_{\text{msw degrad.2011}} = 387.125 \text{[Gg]}
\]

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

\[
Q_{\text{mswundegrad} T} = (Q_{\text{msw } T} + Q_{\text{mswundegrad } T-1}) - Q_{\text{new degrad. } T} \times \text{[Gg]}
\]
\[
Q_{\text{mswundegrad.2011}} = 857.989 - 387.125 = 470.864 \text{[Gg]}
\]

By using the Equation (12), the percentage %TDOCₐₜ has been calculated, as follows:

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

TDOCₐₜ was calculated by using the Equation (5)

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

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

\[
A = Q_{\text{msw degrad. } T} \times %Q_{\text{msw biodegrad. } T} \times k_0 \times \text{[Gg]}
\]
\[
A_{2011} = Q_{\text{msw degrad.2011}} \times %Q_{\text{msw biodegrad.2011}} \times k_0 \times \text{[Gg]}
\]
\( k_0 = 0.185 \) the biodegradable DOC generation ratio, in accordance with [IPCC, 2006], Chapter V, wastes.

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

\[
\% MSW_{\text{biodegrad}} = 51.2
\]

\[
A_{2011} = 387.125 \times 0.512 \times 0.185 = 36.685 [Gg]
\]

\[
B = Q_{\text{msw degrad.11}} \times \% Q_{\text{msw(G+P)degrad.11}} \times k_1 [Gg]
\]

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

\( k_i = 0.1 \), parks and garden wastes DOC generation ratio in accordance with [IPCC, 2006], Chapter V, wastes [7] [9] [10].

\[
\% Q_{\text{msw degrad.11}} = 16
\]

\[
B_{2011} = 387.125 \times 0.16 \times 0.1 = 6.194 [Gg]
\]

\[
C = Q_{\text{msw degrad.11}} \times \% Q_{\text{msw(H+C+text)degrad.11}} \times k_2 [Gg]
\]

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

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

\[
\% Q_{\text{msw degrad.11}} = 16.8
\]

\[
C_{2011} = 387.125 \times 0.168 \times 0.06 = 3.902 [Gg]
\]

\[
D = Q_{\text{msw degrad.11}} \times \% MSW_{(\text{Wood+straw})degrad.11} \times k_3 [Gg]
\]

\[
D_{2011} = Q_{\text{msw degrad.2011}} \times \% MSW_{(\text{Wood+straw})degrad.2011} \times k_3 [Gg]
\]

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

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

\[
D_{2011} = 387.125 \times 0.03 \times 0.03 = 0.384 [Gg]
\]

\[
E = Q_{\text{msw degrad.11}} \times \% MSW_{\text{sludg.degrad.11}} \times k_4 [Gg]
\]

\[
E_{2011} = Q_{\text{msw degrad.2011}} \times \% MSW_{\text{sludg.2001}} \times k_4 [Gg]
\]

\( k_4 = 0.185 \), wastes (containing sludge) DOC generation ratio in accordance with [IPCC, 2006], Chapter V, wastes [9] [10] [17].

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

\[
E_{2011} = 387.125 \times 0.01 \times 0.185 = 0.716 [Gg]
\]

\[
G = Q_{\text{msw degrad.11}} \times \% Q_{\text{msw ind.degrad.11}} \times k_4 [Gg]
\]

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

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

\[
\% Q_{\text{msw ind.degrad.2011}} = 12
\]
$G_{2011} = 387.125 \times 0.12 \times 0.09 = 4.181, [Gg]$

\[
TDOC_{dissolved.T} = \sum [A + B + C + D + E + G] [Gg]
\]

\[
TDOC_{dissolved.2011} = 36.685 + 6.194 + 3.902 + 0.384 + 0.716 + 4.181 = 52.062, [Gg]
\]

\[
Gg = \sum \sum \sum \sum \sum \sum\]

\[
\%

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

\[
%TDOC_{dissolved.2011} = \left( \frac{TDOC_{dissolved.2011}}{Q_{msw \text{ taken into consid.} 2011}} \right) [\%]
\]

\[
Q_{msw \text{ taken in to consid.} T} = Q_{msw \text{ taken in to consid.} 2011} + Q_{msw \text{ taken into consid.} 2011} [Gg]
\]

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

%TDOC_{2001} = 52.062/857.989 \times 0.0607; \ 6.07\%, \text{ respectively.}

The quantity of $\text{CH}_4$ in the year 2011 gas emission is calculated by applying Formula (1) as follows:

$\text{CH}_4_{\text{emission/2011}} = 387.125 \times 0.0607 \times 1.3333 \times 0.5 \times 0.9 \times 0.5 = 7.0494, [Gg]$

where:

- 387.125 [Gg] is MSW degraded quantity of in 2011 which generated DOC and, later on, $\text{CH}_4$
- Methane gas; 6.07%, is the percentage $\% \text{TDOC}$ within landfill body;
- 0.5 represent DOC$\_r$ taking into consideration existing condition from the analyzed emission;
- 1.3333 (16/12) represent C from $\text{CH}_4$;
- 0.9 represents the management level of the analyzed MSW landfill, in the year 2001;
- 0.5 The content [\%] of $\text{CH}_4$ methane gas within Landfill Gas (LFG).

It is to be observed that the $\text{CH}_4$ 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, $\text{CH}_4$ Methane gas:

$\text{CO}_2_{\text{equivalent/2011}} = \text{CH}_4_{\text{emitted/2011}} \times 21 = 148.037[Gg]$

It is to be observed that the $\text{CH}_4$ 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 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 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 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 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 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 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$_x$, NO, Polycyclic aromatic hydrocarbons, HFC, PFC have not been taken into consideration.

The real estimation of the 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), 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 CH$_4$ emission calculation at MSW landfills quantities between $100 \div 200$ (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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