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Inventory of Methane Emissions in the Solid Waste Sector of Ukraine

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Abstract

This report presents the results of a methane inventory in the solid waste sector of Ukraine. It considers the theoretical background of the methane generation process in solid waste, reviews methodologies used for methane generation assessment, and describes the methane inventory process in a transparent way.

This study has been carried out with the purpose of Ukraine's compliance with the requirements of participation in international co-operation over stabilization of GHGs concentrations in the atmosphere. This co-operation should also open new opportunities for Ukraine to substantially improve the energy efficiency of its economy.

Ukraine's solid waste sector is the fourth among other methane emissions sources after natural gas and coal extraction, and enteric fermentation in livestock. The preliminary estimates showed that the solid waste sector in Ukraine generated approximately 4.3% of the total volume of CO_2-equivalent emissions in 1990.

The source of greenhouse gas (GHG) emissions in this sector is the activity of anaerobic bacteria in the waste, which decompose the carbon of organic waste under certain conditions. This results in the generation of landfill gas, which is approximately 50% methane (CH_4).

The inventory of methane emissions from solid waste disposal sites has been conducted according to IPCC guidelines, which have been adapted for Ukrainian conditions and data availability. The calculations were carried out at the level of the administrative regions for the year 2002. The major adjustment of the methodology concerns the fraction of potentially degradable organic components, which has been calculated for each administrative region with consideration of organic industrial wastes.

The results show that methane emissions from solid waste disposal sites in 2002 were 572.5 thousand tonnes (Gg), which corresponds to 12,023 Gg of CO_2-equivalent. The emissions from solid waste disposal sites of cities and towns with populations of more than 200 thousand people were about 285 thousand tonnes or 61% of all methane emissions in the solid waste sector of Ukraine. Most of solid waste disposal sites of the considered towns have sufficient emissions potential to sustain methane recovery, which is a practical way to reduce the anthropogenic impact on climate change and can be an additional energy source.

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Acronyms

CO_2-e	CO_2-equivalent[1]
DOC	Decomposable organic carbon
FOD	First order decay
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
SW	Solid waste
SWDS	Solid waste disposal site
UNFCCC	United Nations Framework Convention on Climate Change

[1] The amount of GHGs can be expressed in CO_2-equivalent, which means that a certain amount of GHG creates the same greenhouse effect as one tonne of CO_2. For example 1 tonne of methane corresponds to 21 tonnes of CO_2-e.

Introduction

In June 1992 more than 150 countries signed the United Nations Framework Convention on Climate Change (UNFCCC) at the Earth Summit in Rio de Janeiro. The Convention entered into force in 1994 after 50 signatories had officially ratified the agreement. UNFCCC requires signatories to prepare inventories of their greenhouse gas emissions sources and sinks. While Ukraine was the 6th largest emitter of greenhouse gases among Annex I (developed) countries, its current emissions are well below their 1990 levels due to the economic recession in the 1990s. Ukraine submitted its first draft inventory to the UNFCCC Secretariat in autumn 1998. Monitoring and reporting greenhouse gas emissions are both key elements of compliance under the UNFCCC, which requires that Ukraine constantly investigates and develops inventories and monitors emissions.

Compliance with UNFCCC requirements is a compulsory precondition of Ukraine's participation in the international process of GHG mitigation. Realization of these commitments will allow Ukraine to estimate its GHG reduction potential, and implement energy efficiency projects and other activities reducing GHG emissions and enhancing their absorption. An additional benefit is that this will allow Ukraine to significantly improve the energy efficiency of its economy.

Two factors impede Ukraine's ability to prepare accurate inventories of GHGs. The first is the lack of statistical data, which makes it extremely difficult to prepare transparent IPCC-compatible inventories. The second is lack of knowledge about global climate change and the purpose and methodology of greenhouse gas inventories at the local level, where data are initially collected.

As part of compliance with commitments of Annex I countries under UNFCCC, the U.S. Environmental Protection Agency through the Pacific Northwest National Laboratory has requested the Agency for Rational Energy Use and Ecology to inventory GHG emissions in Ukraine's solid waste sector and prepare the current report.

The documents of the Intergovernmental Panel on Climate Change (IPCC) show that the solid waste (SW) sector contributes from 5 to 20% into global anthropogenic methane emissions (IPCC, 1996). Ukraine's SW sector is one of the key source categories of GHG emissions as defined by [2] and the SW sector is the fourth among other methane emissions sources after natural gas and coal extraction, and enteric fermentation in livestock. Preliminary estimates showed that the SW sector in Ukraine generated approximately 4.3% of the total volume of CO_2-equivalent emissions in 1990 [13, 14, 15].

The main outcomes of this study are:

- An integrated methodology for assessment of methane emissions in the SW sector of Ukraine has been developed based on the adaptation of the default methodology given in [1, 2].

- Methane emissions in the solid waste sector of Ukraine have been assessed for the administrative regions of Ukraine (autonomous Republic of Crimea and 24 oblasts) for 2002 using the default method and based on three data sources:

  1) National statistics: official census questionnaire 14-MTP "Generation, utilization and supply of recycled materials and waste during 2002";

  2) Our survey results on the annual amount of SW disposal in towns with populations greater than 200 thousand people.

  3) Estimated amounts of solid waste disposed of in solid waste disposal sites (SWDSs), which have been calculated using default values of factors provided by IPCC [1] and urban population numbers by the administrative regions of Ukraine;

- The potential for methane emissions reductions that can be achieved if methane from SWDSs in the above mentioned towns is recovered (flared or utilized) has been estimated.

1 Characterization of the object of GHG Inventory

1.1 General information

The IPCC documents (IPCC, 1996) suggest considering solid waste (SW) disposal as an autonomous source category in GHG inventories. The SW sector is a key source category of GHG emissions in Ukraine considering its contribution to the country's total GHG emissions [12].

In order to assist a GHG inventory in Ukraine, *Proposals to a Concept of the Ukrainian National GHG Inventory System* [12] have been developed. This document suggests the terms and prioritization for carrying out detailed GHG inventories in key source categories of GHG emissions to ensure Ukraine's participation in international activities on climate change mitigation. According to methodological guidance [2] a key source category is one that is prioritized within the national inventory system because it is estimated to have a significant influence on a country's total GHG inventory in terms of the absolute level of emissions. These include economic sectors that account for 95% of cumulative country's GHG emissions with a 90% probability. The largest emissions source in Ukraine is the energy sector, followed by industrial processes and construction, metallurgy, natural gas and coal extraction, agriculture and solid waste.

Among methane emissions sources the SW sector is the fourth after natural gas and coal extraction and, enteric fermentation in livestock. The preliminary estimates showed that the SW sector in Ukraine generated approximately 4.3% of the total volume of CO_2-equivalent emissions in 1990 [14].

1.2 Methane as a Greenhouse Gas and an Energy Source

Methane (CH_4) is an important greenhouse gas and a major environmental pollutant. Methane is also the primary component of natural gas and, as such, can be a valuable energy source. Since methane is a source of energy as well as a greenhouse gas, reducing methane emissions from SWDSs is economically beneficial. Methane emission reduction strategies offer one of the most effective means of mitigating global warming in the short term for the following reasons [3]:

- Methane is one of the principal greenhouse gases, second after carbon dioxide (CO_2) in its contribution to global warming. In fact, methane is responsible for roughly 18 percent of the total contribution in 1990 of all greenhouse gases [3]. On a kilogram for kilogram basis, methane is a more potent greenhouse gas than CO_2 (about 21 times greater over a 100 year time frame) [16];

- Methane concentrations in the atmosphere have risen rapidly. Atmospheric concentrations of methane have been increasing at about 0.6 percent per year [5] and have more than doubled over the last two centuries [6]. In contrast, CO_2 atmospheric concentration is increasing at about 0.4 percent per year;

- Reductions in methane emissions will produce substantial benefits in the short run. Methane has a shorter atmospheric lifetime than other greenhouse gases - methane lasts around 11 years in the atmosphere, whereas CO_2 lasts about 120 years [7]. Due to methane's high potency and short atmospheric lifetime, stabilization of methane emissions will have an immediate impact on mitigating climate change.

The unique characteristics of methane emissions make methane recovery one of the most attractive and efficient ways to mitigate climate change.

1.3 Landfills as a Source of Methane Emissions

Methane is generated in SWDSs as a direct result of the natural decomposition of solid waste under anaerobic (in the absence of oxygen) conditions [1-3]. The organic component of landfill waste is decomposed by bacteria in a complex biological process that produces methane, carbon dioxide, and other trace gases. High levels of organic materials in the waste enhance the amount of landfill gas. It should be noted that CO_2 emissions from landfills do not contribute to the increase in CO_2 abundance in the atmosphere because the carbon in the CO_2 is of recent biogenic origin (e.g., from crops and trees). Estimates of global methane emissions from SWDSs range from 20 to 70 millions tonnes per year, accounting for about six to twenty percent of total annual anthropogenic methane emissions [7].

The process of decomposition of organic matter depends on a number of factors. Microbial populations, which actually produce methane, vary significantly among landfills due to differences in conditions [8]. Consequently, characteristics of landfills influence the generation of methane and its emission from SWDSs [1-3]. The key factors that determine methane production are:

- Waste composition. Methane is produced from the organic component of solid waste (e.g., food scraps, paper, and other biodegradable materials). The decomposition (fermentation) of this organic material leads to methane emissions. Therefore, high levels of organic materials in the waste increase the amount of landfill gas and the share of methane in it. Different countries and regions are known to have SW with widely differing compositions: wastes from developing countries are generally high in food and yard wastes, whereas developed countries, especially North America, have a very high paper and cardboard content in their SW. Landfills in developing countries will tend to produce gas quickly (completing methane production within 10-15 years) because putrescent material decomposes rapidly. Landfills with a high paper and cardboard content will tend to produce methane for 20 years or more, at a lower rate. If SWDSs have large quantities of construction and demolition debris, they will generate less methane then would otherwise be expected.

- Anaerobic environment. In order to produce methane, organic material must break down in an anaerobic environment (i.e. in the absence of oxygen). Deliberate covering of solid waste with dirt in a landfill leads to the creation of anaerobic conditions. Similarly, the organic material in large open dumps becomes effectively covered by the other waste, thereby leading to anaerobic conditions and methane generation. Waste compaction also reduces the availability of oxygen, thus creating favorable conditions for methane generation. The density of uncompacted domestic waste as delivered to the site is in the range of 200 to 400 kg/m^3. This will rise upon placement to approximately 600 kg/m^3 (excluding cover), or, on average, 800 kg/m^3. This may rise further on compaction and settlement to 1000 to 1200 kg/m^3. Geological conditions may also affect the access of air, e.g. if SWDS is located in a "hole" in the ground, which could be a natural depression (e.g., pits or canyons) or man-made.

- Moisture content. Moisture is essential for anaerobic decomposition (i.e., fermentation). Water provides the medium for cell growth and metabolism, and transportation of nutrients and bacteria within the landfill. The moisture content will depend on the initial moisture content of the waste, the extent of infiltration from surface and groundwater sources, and the amount of water produced as a result of waste decomposition.

- Acidity and chemical composition of SW. Living systems are sensitive to pH (a measure of acidity) and hazardous chemicals. The optimal pH for methane production is between 6.8 and 7.2. Methane production decreases sharply with pH values below 6.5. If hazardous materials are mixed with the SW, methane generation may be hampered and the recovered gas may contain trace quantities of hazardous chemicals.

- Temperature. Methanogenic bacteria are affected by temperature. The rate of methane production is maximized between 50^0 and 60^0 C (120^0 to 140^0 F), but can occur anywhere from between 10^0 to 60^0 C (50^0 to 140^0 F) [17]. Typically in landfills and large open dumps, the waste decomposition process provides enough heat to maintain suitable temperatures for methane production to take place in the range of 25^0-40^0 C regardless of the ambient surface temperatures [1].

In addition, the refuse consistency, the landfill design and area, availability of liquid control (surface drainage, facilities to control leachate, flooding or "ponding") and other site-specific factors can affect the quantity and rate of methane generation.

These conditions should be taken into account when assessing methane emissions from SWDSs and reflected in the appropriate coefficients. Below is the classification of SWDSs obtained by dividing them according to the availability of anaerobic conditions for methane generation.

1.4 Characterization of Solid Waste Disposal Sites as Methane Emissions Inventory Objects

Solid waste disposal sites can be divided into "managed" (landfills) and "unmanaged" (large open dumps[1]) according to the extent and type of active site management carried out [3]. Waste in rural areas is typically scattered on the land rather than deposited in a SDWS, hence it tends to decay aerobically generating extremely low, if any, CH_4 emissions.

A managed SDWS has controlled placement of waste (i.e., waste directed to specific deposition areas, a degree of control over scavenging, and a degree of control over fires) and includes at least cover material and/or mechanical compacting or leveling of the waste [1]. All other SDWSs that do not fall into the above category – large open dumps – are defined as unmanaged sites. Unmanaged sites are further divided as deep (≥5m depth) or shallow (<5m depth), to allow for their CH_4 generation potential.

Landfills (or managed SWDSs) are designed specifically to receive wastes. Their design reflects a precise engineering component that allows for the controlled disposal of waste [1-3]. Landfill design and management are becoming increasingly sophisticated in many countries, as the environmental consequences of uncontrolled dumping are better understood. New landfill design standards in many countries are ensuring that landfills are lined before receiving waste, and also have provisions for the safe control, and removal where appropriate, of gas and leachate generated. Good waste management practices ensure that waste is compacted to minimize void space. All these factors can encourage the rapid development and maintenance of anaerobic conditions within the landfill, and result in a higher methane production. A schematic of a typical closed landfill is presented in

- Figure 1 [3].

[1] *Revised 1996 IPCC Guidelines for National GHG Inventories* does not distinguish between "landfills" and "open dumps", but uses a continuum of SWDSs, characterised by the degree of waste management and depth.

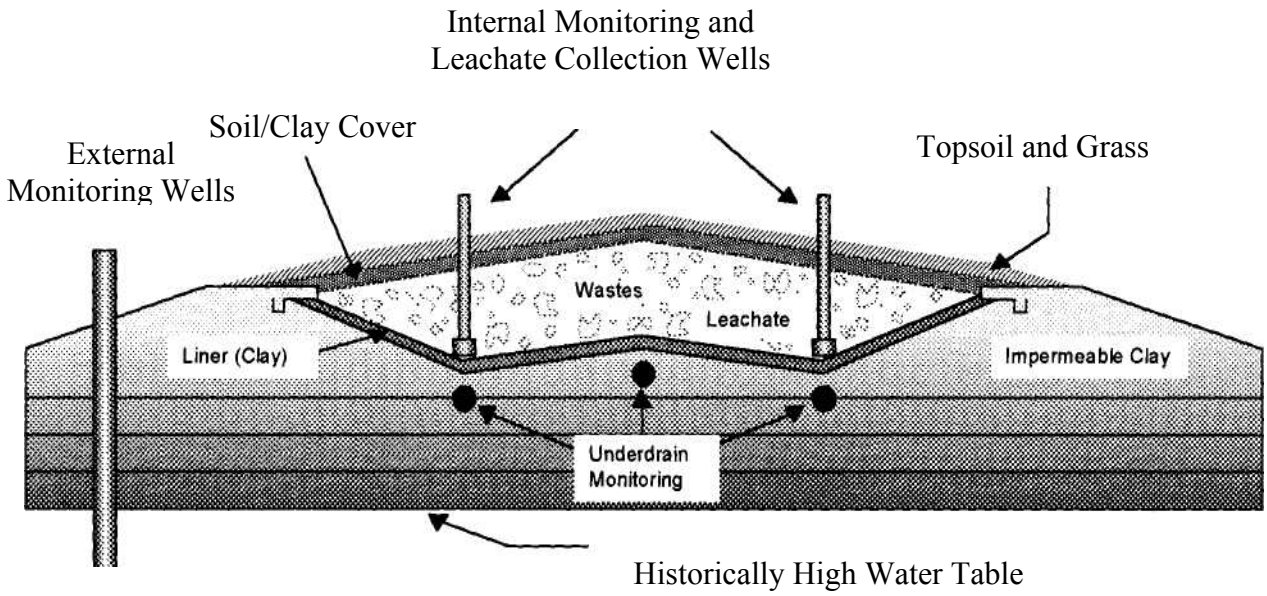

Figure 1. Schematic of a Typical Closed Landfill

- Open dumps (or unmanaged SWDSs) are sites that have been deemed appropriate for waste disposal. Open dumps are generally only loosely compacted, and with no provision for control of any pollutants generated, where scavenging by animals and humans can remove much of the biodegradable wastes [1]. The depth of open dumps influences methane generation through differences in access of air and the density of SW. Wastes in shallow open dumps (<5 m) generally decompose aerobically, producing little methane. However, there is some evidence that some methane production does occur. [3]. In deep unmanaged SWDSs (≥ 5m) the conditions for methane production are more favorable as the layers of waste at the top prevent access of air to lower layers creating anaerobic conditions. Furthermore, waste near the bottom of a deep open dump is usually more compacted then in a shallow one.

Therefore, open dumps should be included in the inventory of methane as they produce methane, although less then managed landfills. Additionally, some open dumps are being rehabilitated and upgraded to "landfill status" and may be considered as managed SWDSs.

2 Methodology of Methane Emissions Inventory in the Solid Waste Sector

2.1 Overview of the Methodologies of Methane Emissions Inventory in the Solid Waste Sector

The national inventory requirements are stated in the IPCC Guidelines [1]. The primary objective of this document is to determine the sequence of calculations and the format of the results in order to keep a single inventory format in different countries and regions and to enable

the comparison and verification of the results. Guidelines [1] provide for two methods: the default method and the First Order Decay (FOD) method.

The default method provides an estimate of existing average annual emissions. This method assumes that methane is released from SW in the year that the waste is disposed of [1]. However, this is not true as methane generation from SW occurs after a certain period of time from its disposal to when anaerobic conditions are created, and continues over several years.

Nevertheless, the default method gives a reasonable estimate of the current years' emissions if the amount and composition of the waste disposed of has been relatively constant over the previous several years [1]. However, if there have been significant changes in the rate of waste disposal, this method is unlikely to give a good estimate of current methane emissions. For example, if the fraction of decomposable organic carbon in SW disposed of decreases over time, the method will underestimate the emissions, as it assumes that the content of carbon in previous years was similarly low.

Factors used in the default method are calculated on the basis of:

- Data on the total volume of SW disposed of in SWDSs of different types during the inventory year;
- The fraction of decomposable organic carbon and its share that is actually degraded;
- The fraction of CH_4 in the landfill gas.

The FOD method is more precise by taking the time component into account. This increases the accuracy of results, allowing for the degradation processes that occurs over time.

The main difference between these two methods is that the FOD method gives a time-dependant methane emissions profile that better reflects the true pattern of the degradation process over time, whereas the default method is based on the assumption that all potential methane is released in the year of waste disposal [2].

The Good Practice Guidance [2] also suggests the two above-mentioned methods. The use of the FOD method requires historical data on quantities of SW disposed of in SWDSs, its composition and management practices for the last several decades. The default method is used when such data are unavailable.

There are also other methodologies developed for specific tasks. For instance, A Guide for Methane Mitigation Projects published by the US Environmental Protection Agency in 1996 [3] was designed to assist the development of methane utilization projects. It provides a methodology for estimating methane emissions from SWDSs for the purpose of identifying cost-effective projects.

This methodology recommends that the research is carried out in two stages: (1) identification of SWDSs, which can support cost-effective methane utilization projects, and (2) the estimation of methane emissions at these SWDSs. It suggests three approaches for estimating methane emissions from SWDSs:

- Drilling test wells

- A rough estimation method, which is based on average amount of methane production from a unit of SW. This method does not take into account waste composition, local climate conditions and other parameters

- Model estimations:

    1. FOD Model, which is similar to that used in the Good Practice [2]. However, unlike the Good Practice, the FOD Model suggests using an average potential methane generation that does not change over time

    2. Waste in Place Model was developed from data on gas recovery projects in the United States [3]. This model relates to the quantity of waste in a SWDS, but does not consider the aging of the waste and the changing rate of gas production over time.

The US Agency for Environmental Protection has recently improved the estimation process for the cost-effectiveness of methane utilization at SWDSs [4]. This methodology is targeted at state and local authorities in the USA.

2.2 The Methodology of Methane Emissions Inventory in the Solid Waste Sector of Ukraine

The assessment of methane emissions in the solid waste sector of Ukraine have been carried out for the administrative regions of Ukraine for 2002 using the default method and based on three data sources:

- National statistics: official census questionnaire 14-MTP "Generation, utilization and supply of recycled materials and waste during 2002";

- Our survey results on the annual amount of SW disposal in towns with the population more than 200 thousand people;

- In some cases, the estimated amounts of solid waste disposed of at SWDSs, which have been calculated using default factors provided by IPCC [1] and urban population numbers in the administrative regions of Ukraine.

The sequence of calculations in the inventory of methane emissions from SWDSs in the context of the administrative regions of Ukraine is the following:

1 Determination of the total amount of SW disposed of in SWDSs in the inventory year

2 Calculation of methane generation rate

2.1 Calculation of total weighted average methane correction factor

2.2 Calculation of methane generation potential

2.2.1 Determination of fraction of potentially degradable waste in SW

2.2.2 Determination of fraction of decomposable organic carbon (DOC) in SW

3 Assessment of annual methane generation based on the methane generation rate of the SW

4 Withdrawing the amounts of recovered methane.

Methane emissions from SWDSs can be calculated as shown in Equation 1:

$$V^*_{ri} = (M_{ri} Q_{ri} - R_{ri})(1 - q), \quad (1)$$

where:

V^*_{ri} – methane emissions generated from SWDSs, Gg/yr [1]

r – administrative region index

i – SWDS type

M_{ri} – total solid waste disposed to SWDSs in region i, Gg/yr

Q_{ri} – methane generation rate[2]

R_{ri} – methane recovered in the inventory year, Gg/yr

q – oxidation factor, generally used the default value of 1 minus 0, as suggested by the IPCC [1, 2].

It should be noted that CH_4 recovered (R_{ri}) must be subtracted from the amount of generated methane before applying the oxidation factor, because only landfill gas that is not captured is subject to oxidation in the upper layer of the landfill. Also, the methane generation rate should be expressed in weight in Gg CH_4/Gg waste and not volume (m^3/Mg waste) as pointed in [1] in order to make the results of the default and FOD methods compatible.

All aforementioned factors can change over time, depending on waste disposal trends and waste management practices. The calculation of these factors using Ukrainian data is given in section 2.3 below.

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[1] Instructions on completing worksheets for automatic calculation of methane emissions in the SW sector of Ukraine are given in Section 4.

[2]The choice of factors used for calculations under the default method is justified in Section 3.2.

2.3 Calculation of Factors For Methane Inventory in the Solid Waste Sector

If reliable data on the **amount of solid waste** disposed of in a region are unavailable it can be calculated from urban population numbers and default values of daily SW generation and disposal rates per person [1, 2]. Since Ukraine's rural population is assumed to dispose of waste in such a way that methane emissions are extremely low [1] and SW disposed to SWDSs mainly comes from cities and towns, only data on the number of urban residents are used in the calculation.

The annual amount of SW disposed of in SWDSs in an administrative region (r) of Ukraine can be calculated from Equation 2:

$$M_i = \mu N_r \, m_r \, 10^{-6} \, 365, \qquad (2)$$

where:

M_i – total SW disposed of to SWDSs, Gg/yr

μ – SW Generation Rate, kg/capita/day

N_r – urban population of the region (r) of Ukraine

m_r – the fraction of SW disposed of to SWDSs

10^{-6} – conversion factor from kilograms into thousands of tonnes (Gigagrams)

365 – the number of days in a year.

Default values of average daily SW generation rate (μ) and the fractions of SW disposed of in SWDSs (m_r) are provided in [1] Table 6-1 for many countries. However, Ukraine is not presented in this table. The methodology [2] recommends that default values from a country that most closely reflects Ukraine's conditions should be used instead. Therefore, the default values for Russia are used in the calculations: SW Generation Rate (μ) – 0.93 kg/cap/day; the fraction of SW disposed to SW disposal sites (m_{ri}) – 0.94.

In order to obtain the **methane generation rate** from SWDSs in an administrative region of Ukraine, the following data should be taken into account:

- SW distribution among SW disposal sites of different types, which are utilized in the administrative area of Ukraine;
- SW composition – the fraction of Decomposable Organic Carbon (DOC) in SW; and
- The fraction of DOC than is released as methane.

The per unit of waste realized in a region of Ukraine (r) from the type of SWDSs (i) can be calculated as follows:

$$Q_{ri} = \frac{16 H_r U_{ri} f}{12}, \quad (3)$$

where:

Q_{ri} – methane generation rate

H_r –total weighted average methane correction factor, fractions

U_r – methane generation potential, i.e. the fraction of carbon in SW that can be released

f – the fraction of methane in landfill gas produced by SWDSs, the default value of this factor suggested by the IPCC [1, 2] is 0.5

16/12 – conversion ratio that converts the weight of carbon into that of methane.

The calculation of the **total weighted average methane correction factor** (H_r) in the administrative region (*r)* of Ukraine requires the information on proportions of SW[1] (by weight) of each of the three types of SWDSs described in section 1.4. It is calculated as a sum of the weighted average methane correction factors for each type of SWDS. The weighted average methane correction factor (H_{ri}) for *(i)* type of SWDS equals the fraction of SW disposed multiplied by its respective methane correction factor. The total weighted average methane correction factor can be therefore calculated as the sum of multiplied fractions of SW disposed to each SWDSs type (i) and respective methane correction factors:

$$H_r = \Sigma h_{ri} = \Sigma \eta_{ri} \xi_{ri}, \quad (4)$$

where:

H_{ri} –total weighted average methane correction factor

h_{ri} – weighted average methane correction factor for the *(i)* type SWDSs, fractions

η_{ri} – SW disposed to the *(i)* type SWDSs, fractions

ξ_{ri} – methane correction factor for the *(i)* type SWDS

Default values for the methane correction factor (ξ_r) suggested by [1, 2] should be used when no national data are available (see table 1).

If there is data available on annual waste disposal to individual SWDSs and their type, the methane correction factor may be obtained for each SWDS if necessary. In this case, the factor

[1] The sum of values of proportions should always be 1.

simply equals a respective default value given in table 1, unless local experimental data for a particular site/type is available.

Table 1. Default Values of Methane Correction Factor for Different Types of Sold Waste Disposal Sites

Type of Site	Methane Correction Factor
Managed	1
Unmanaged deep (≥ 5 m waste)	0.8
Unmanaged shallow (< 5 m waste)	0.4

If no national data on the solid waste distribution among different types of SWDSs are available, the default value of factor (η_r) suggested by methodology [1, 2] is 1, and for the weighted average methane correction factor (ξ_r) is 0.6, therefore the total weighted average methane correction factor is 0.6 as well.

According to our survey (see section 3.1), the majority of SWDSs (55.7% of reported sites) are unmanaged deep (>5m waste), so the methane correction factor used for them is 0.8. The second largest group is managed sites (43.9%) with the factor of 1. Only 2 SWDS in the town of Krivyj Rig (Dnipropetrovsk region) are unmanaged shallow (waste level is less than 5 m) with the methane correction factor of 0.4. Hence, the total weighted average methane correction factor is about 0.89, which is higher than the default value.

Methane generation potential (U_r) in an administrative region (r) of Ukraine reflects the fraction of carbon in the total SW, which can be released from its organic components. It can be obtained in one of the following ways:

- From national sources – if there were national studies on this subject
- Calculated using the default values: the **fraction of Decomposable Organic Carbon (DOC)** in SW should be multiplied by the fraction of DOC that actually degrades. Methodology [1] suggests the default value of the fraction of DOC in municipal solid waste for Russia 0.17 (no value for Ukraine is available). The default value of the fraction of DOC that actually degrades is 0.77 for all countries[1]. Therefore, multiplied together these give the default methane generation potential of 0.1309.

[1] This is correct for the assumption that the temperature in the anaerobic zone of a SW landfill remains constant at about 35° C regardless of ambient temperature [2]; this value is currently under review.

- Calculated using national data on waste composition: by multiplying together the fraction of DOC that actually degrades (the default value is 0.77) and the sum of the product of the **fractions of potentially degradable organic components in SW** and their respective DOC values [1, 2]. This is reflected in Equation 5:

$$U_r = 0.77 \, \Sigma \, D_{rc} \, d_c \, , \qquad (5)$$

where:

0.77 – the fraction of DOC that actually degrades

D_{rc} – the fraction of a potentially degradable organic component (waste steams) of (c) type in SW

d_c – the fraction of DOC in a potentially degradable organic component of (c) type.

Table 2. Default DOC Values for major solid waste streams (adapted from [1]).

Potentially degradable organic components (major waste steams)	Fraction of DOC in a potentially degradable organic component
Paper and textiles	0.4
Food waste	0.15
Wood and straw[1]	0.3

So, in order to calculate methane generation potential (U_r) of SW in an administrative region (r) of Ukraine, the fraction of each potentially degradable organic component should be first calculated and multiplied by its respective DOC value. Considering the format of Ukraine's official statistics and data available (see section 3.1), the fractions of 17 waste types have been calculated (see Annex 1). The following correspondence of DOC values and potentially degradable organic waste types have been accepted for the calculations: 'Paper and textiles' obviously includes columns 1 and 2 of the table in Annex 1; ‘Garden waste, park waste, and other (non-food) organic putrescibles’ includes column 3; the default DOC value of 0.17 suggested for Russia is used for municipal solid waste; 'Food waste' embraces waste streams in columns 5, 6, 7, 9, 10, 11, 12, 14; and the default value for 'Wood and straw' is applied for columns 8, 13, 15 and 16. After multiplication, the values are summed and multiplied by the factor of 0.77 (the fraction of DOC that actually degrades).

[1] Excluding lignin carbon.

3 Input data and Factors for Methane Emissions Inventory in the Solid Waste Sector of Ukraine

3.1 Sources of Data for Methane Emissions Inventory in the Solid Waste Sector of Ukraine

As mentioned above, methane is generated in SWDSs as a result of a complex process involving the activity of anaerobic bacteria. This requires a number of conditions such as the presence of organic matter, maintenance of a certain temperature, and the absence of oxygen (section 1.2). The amount of methane generated depends on several factors: metric parameters of SWDSs (their depth, compaction, management practices), and SW disposal rates and composition.

Thus, in order to inventory methane emissions from the SWDSs the following information is required:

- Availability of inventory objects (SWDSs);
- SW composition: the presence of organic matter and its fraction in typical SW;
- The amounts of SW disposal.

The sources of input data are:

- Official census questionnaire 14-MTP "Generation, utilization and supply of recycled materials and waste during 2002" [11] provides data on the amounts of recycled materials and industrial waste generation, external supply, utilization, destruction and disposal to SWDSs in the context of administrative regions and Ukraine as a whole;
- Statistical yearbook of Ukraine, Table 16.3 "Available Population by Place of Residence and Age, by Region" [18] provides data on urban population that is used for the calculation of annual SW disposal.
- Survey results that provide information on individual SWDSs in cities and towns with population over 200 thousand people, including waste disposal, its composition (in some cases), depth of a landfill and management practices.

The form 14-MTP provides the information on recycled material types and industrial wastes, including organic wastes (each type of waste in presented in a separate table) and municipal solid waste by the administrative regions of Ukraine and the whole country (in tonnes). According to Ukrainian legislation, the State Statistics Committee of Ukraine is prohibited from giving any information about individual enterprises, including their waste generation and disposal. However, the form provides data on the number of enterprises generating recycled materials and waste, and the total quantities of:

- Waste available at the enterprises at the beginning of the reporting period,
- Waste generated by the enterprises during the reporting period,

- Waste received from other enterprises,
- Utilized waste and recycled materials,
- Supplied (sold) recycled materials,
- Waste or recycled materials available at the end of the reporting period, and
- Recycled materials and waste destroyed or disposed of to SWDSs.

For methane inventory in the SW sector, only the latter information for organic industrial wastes is relevant. It should be noted that data on municipal solid waste is presented as one category without specification of its content and the fraction of organic components. The information on characteristics (types) of SWDS is not collected by the State Statistics Committee of Ukraine.

A more comprehensive source of input data may be the survey of utility enterprises or Regional Authorities on Ecology and Natural Resources, whose terms of reference cover monitoring of SWDSs. If conducted properly (and respondents took it seriously), such a survey may give all required information at the level of individual SWDSs.

3.2 Preparation of input data

3.2.1 General information

Since data on solid waste disposal was available from different sources, the assessment of methane emissions has been carried out in three versions based on:

- Official statistics – data from form 14 MTP. This form has to be filled out by each enterprise in Ukraine, where it has to state its annual amounts of waste by type disposed of in SWDSs. This data is summarized by the statistics of authorities and presented for each administrative region of Ukraine.
- Our estimate of SW generation and disposal based on urban population numbers of a region and default values of daily SW generation and disposal rates per person (see page 14 for the method).
- The annual amounts of municipal SW disposed of in SWDSs of cities and towns with the population more than 200 thousand people. These data were obtained in our survey, where Regional Authorities on Ecology and Natural Resources were asked to provide detailed information about each SWDS in cities and towns in their region. The key questions were to assess the amount of SW disposed of to SWDSs in 2002, and waste compaction and composition.

Table 3 shows the data on the amounts of SW disposal obtained from these three data sources. Official statistics are provided for both the total amount of solid waste (includes

municipal and industrial organic wastes) and municipal waste separately to make it comparable with the survey data and estimates, which include municipal waste only.

Table 3. Amounts of solid waste disposed of to solid waste disposal sites in 2002 by the administrative regions of Ukraine from different data sources, Gg

Administrative Regions of Ukraine	Official Statistics		Survey Data	Estimated Amount of Solid Waste
	Total Amount of Solid Waste	Municipal Solid Waste		
Crimea	67.8	61.4	128.3	403.9
Vinnitsia Region	347.2	0.7	125.0	260.5
Volyn Region	127.7	96.1	81.3	169.1
Dnipropetrovsk	178.1	155.5	373.0	936.1
Donetsk Region	10,752.8	10,735.3	811.8	1,373.6
Zhytomyr Region	177.8	132.6	75.0	245.5
Transcarpathian	33.0	10.3	52.0	148.2
Zaporizhzhia Region	340.2	324.4	314.8	461.0
Ivano-Frankivsk	71.1	10.2	63.7	188.7
Kyiv Region	74.4	13.6	46.0	334.8
Kirovograd Region	85.3	75.9	54.0	214.9
Lugansk Region	309.1	299.6	71.0	688.7
Lviv Region	281.4	214.4	230.0	495.7
Mykolaiv Region	129.3	84.9	152.6	265.3
Odesa Region	329.9	319.2	300.0	514.5
Poltava Region	307.0	272.0	291.4	302.6
Rivne Region	104.5	97.4	96.0	174.8
Sumy Region	236.5	109.3	74.8	265.5
Ternopil Region	249.3	69.8	80.0	154.3
Kharkiv Region	203.4	91.0	200.0	725.0
Kherson Region	11.8	6.5	94.2	223.1
Khmelnytsky Region	270.8	213.9	80.0	231.8
Cherkasy Region	115.4	68.8	20.5	238.6
Chernivtsi Region	123.2	101.5	31.8	119.1
Chernigiv Region	199.2	153.0	100.0	229.9
City of Kyiv	443.2	439.7	375.0	836.5
City of Sevastopol	85.5	84.6	108.0	113.9
UKRAINE	15,655.0	14,241.6	4,430.1	10,315.4

The analysis of the data in Table 3 shows a certain discrepancy among these three data sources. This may be explained by several reasons:

- Delays in reporting of enterprises on SW disposal in the official census

- Municipal waste disposal transport sometimes may also provide services to local industries, whereas in the 14 MTP form they state it all as 'municipal solid waste'

- The level of municipal services and living standards vary among towns and cities. Therefore, waste generation and disposal per person may be very different in a city with a population of more than a million people than from those in a small town.

This inventory used the data of the national statistics on organic waste disposal by industries (wood processing, textile, food etc. presented in Annex 2) because it `is based on the official census, which is submitted by each enterprise producing waste. The choice of data source for municipal solid waste and its justification is given in section 3.2.2 below.

3.2.2 Selection of input data on solid waste disposal

As mentioned above, several data sources were used for methane inventory in the SW sector of Ukraine. The analysis of these data shows not only differences among them, but also some trends: the estimates of SW disposal based on population numbers are generally higher than official statistics on municipal solid waste Figure 2. The only exception is Donestk region, where official statistics suggest an unrealistically high figure for municipal waste disposal (see Figure 3). This may be explained by an assumption that respondents of the official census questionnaire may include in the 'municipal solid waste' category other types of SW (e.g. some industrial wastes[1]).

[1] Donetsk region is known in Ukraine for its metallurgy, coal mining, extraction and refinement of other resources

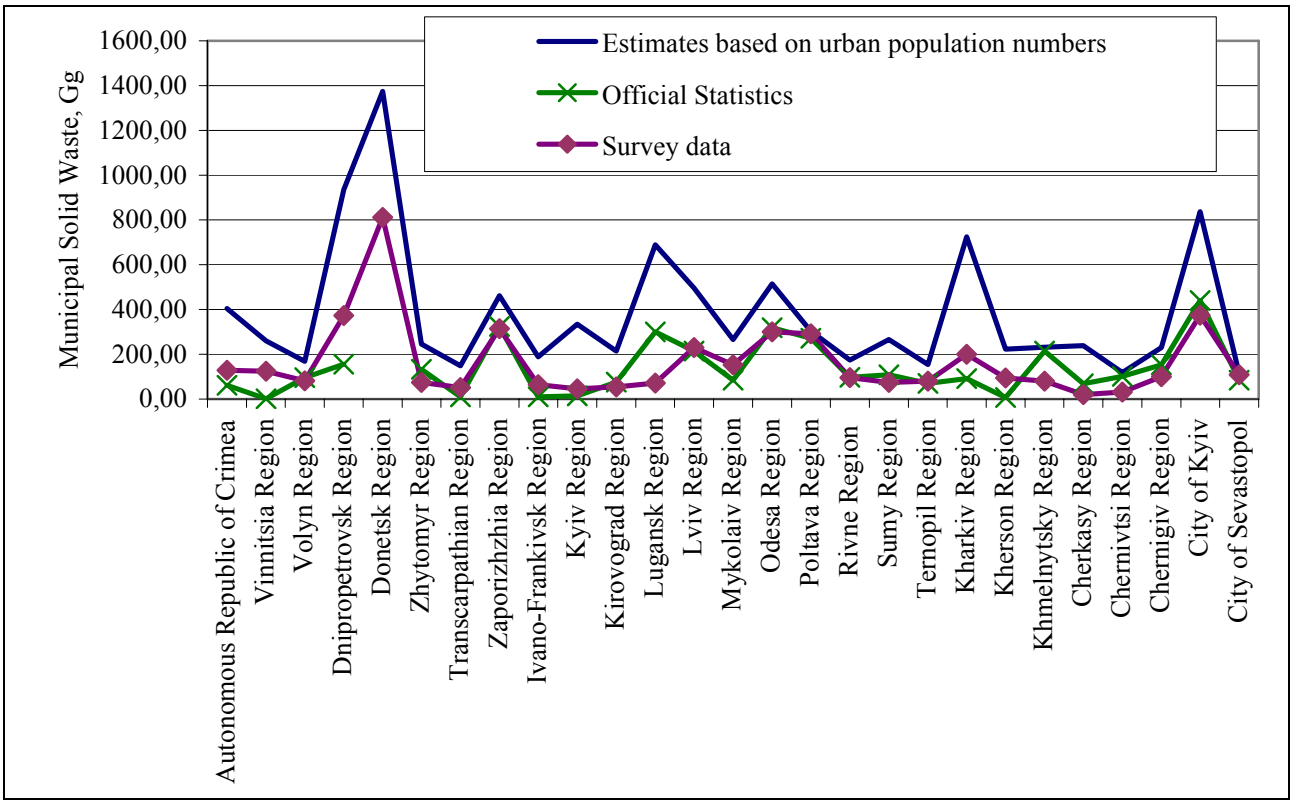

Figure 2. Annual municipal waste disposal in 2002 by regions of Ukraine according to different data sources (the figure from official statistics for the Donetsk region of is not shown here).

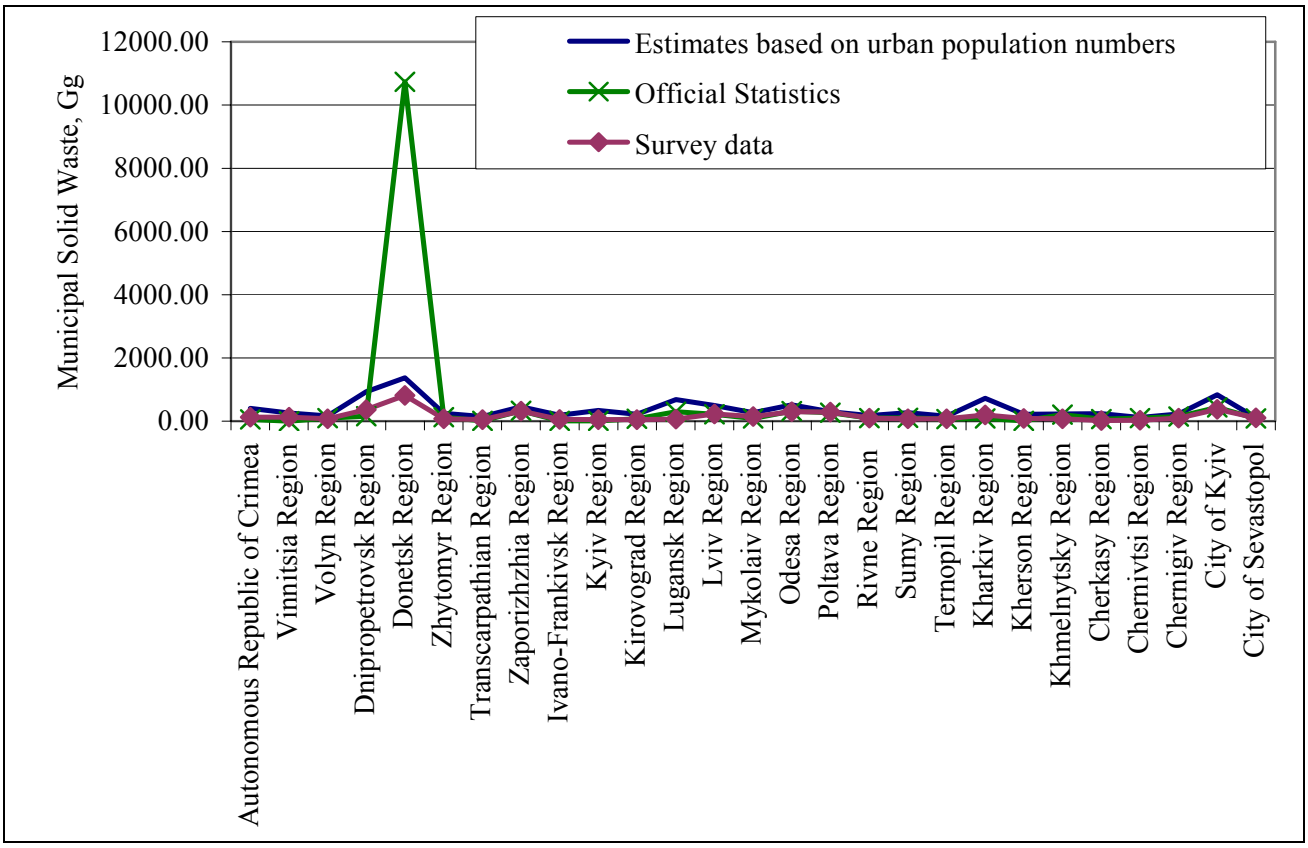

Figure 3. Annual municipal waste disposal showing the figure from official statistics for the Donetsk region.

Considering the above differences, the amounts of municipal solid waste need to be corrected in some cases. In regions where the amounts of SW from official statistics are less than those of the survey, the latter has been accepted for the inventory. It is assumed here that lesser values do not reflect the full amount of SW disposed of in a region.

Data selected for the inventory of methane from SWDSs in Ukraine is presented in Annex 2. All data on organic industrial wastes are adopted from the official statistics based on the the 14 MTP form. Data on municipal solid waste are primarily taken from the national statistics, and partially from the survey in cases where the latter showed greater amounts of SW disposal than the official statistics for respective regions. These administrative regions include the Autonomous Republic of Crimea, Vinnitsia, Dnipropetrovsk, Transcarpathian, Kyiv, Lviv, Mykolaiv, Poltava, Ternopil, Kherson, Kharkiv regions, and the city of Sevastopol.

Estimates of the amounts of SW based on population and the average waste generation rate seem to be overstated. This may be explained by the fact that not all urban populations generate and dispose of SW in the same manner (see also 3.2.1) (e.g. part of the population of small towns

does not dispose SW in SWDSs). Hence, these estimates are used mainly for comparison purposes and not for methane inventory.

An exception has been made for the Donetsk region, where the amount of municipal solid waste disposed of in SWDSs according to the official statistics is significantly higher than that according to both the survey and estimates (see Figure 3). The value suggested by the national statistics is clearly exaggerated because this would mean an average daily municipal waste generation rate of 7.347 kg/person, which seems to be unrealistic and is much higher than in any developed country, let alone Russia with 0.93 kg/person [1]. At the same time, this region is very urbanized, whereas survey data are available for only 4 cities and towns of the region (Donetsk, Makiivka, Horlivka and Mariupol) and their sum shows lesser amount of SW disposal than the estimates. Therefore, in this case the estimate of annual SW disposal based on population numbers and the default rate of SW generation has been used in the inventory.

4 Inventory of Methane Emissions In The Solid Waste Sector of Ukraine

4.1 Results of calculations of methane emissions in Ukrainian solid waste sector based on different data sources.

The results of calculations of methane emissions are presented in Table 4. The left column shows the results obtained based on the pre-selected data (see section 3.2.2 above), whereas the right column reflects the emissions from SWDSs included in the survey only. It should be noted that the left column takes into account industrial wastes mentioned in the official statistics, whereas the survey represents emissions from municipal solid waste only.

Table 4. Results of Inventory of Methane Emissions in the Solid Waste Sector of Ukraine in 2002

Administrative Regions of Ukraine	Methane Emissions Based on Pre-selected Data by Administrative Regions, Gg	Methane Emissions Based on Survey Results by Towns, Gg
Crimea	10.750	8.058
Vinnitsia Region	34.801	6.981
Volyn Region	10.346	5.105
Dnipropetrovsk Region	31.959	21.244
Donetsk Region	108.642	53.998
Zhytomyr Region	16.160	5.236
Transcarpathian Region	7.132	3.630
Zaporizhzhia Region	27.259	14.800
Ivano-Frankivsk Region	12.857	4.447
Kyiv Region	9.014	2.409
Kirovograd Region	6.946	3.393
Lugansk Region	24.474	4.949
Lviv Region	23.615	13.649
Mykolaiv Region	15.763	12.651
Odesa Region	26.073	18.326
Poltava Region	26.949	18.114
Rivne Region	8.501	6.702
Sumy Region	17.996	5.875
Ternopil Region	18.534	6.562
Kharkiv Region	24.905	15.708
Kherson Region	7.740	5.130
Khmelnytsky Region	21.336	5.585
Cherkasy Region	9.655	1.104
Chernivtsi Region	10.790	2.359
Chernigiv Region	17.447	6.981
City of Kyiv	34.472	22.236
City of Sevastopol	8.419	9.406
UKRAINE	**572.536**	284.639

4.2 Potential for GHG emissions reductions due to the recovery of methane from solid waste disposal sites in Ukraine.

Landfill gas consists of about 50% of methane, which can potentially be a source of energy. For the purpose of climate change mitigation, this methane can be flared or utilized for energy production. When flared, methane is converted into other GHGs, most of which is carbon dioxide (over 90%). As mentioned in section 1.2, the greenhouse effect of CO_2 is 21 times less than that of CH_4, thus flaring converts methane into a less harmful substance.

Utilization of landfill gas is more efficient. In this case methane is not simply replaced by carbon dioxide, but also it replaces natural gas (which is a fossil fuel) that would have been otherwise burnt for energy generation or other use. Hence, landfill gas utilization also reduces GHG emissions from fossil fuel consumption. Landfill gas is a product of decomposition of organic material of recent biogenic origin, and, therefore, is renewable resource. In other words, there are no net GHG emissions into the atmosphere from landfill gas combustion. Furthermore, when landfill gas is utilized to replace natural gas or other fossil fuels, there are two sources of GHG emissions avoided. One is CH_4 emissions from landfills (which is avoided in flaring) and the other is CO_2 emissions from fossil fuel combustion.

The amount of methane from SWDSs in cities and towns with population over 200 thousand people is 285 thousand tonnes (Gg), which is about 61% of all methane emissions from SWDSs in Ukraine. However, not all of these landfills have sufficient methane emissions for cost-effective utilization. According to [3], shallow SWDSs (<5m) generate too little landfill gas for cost-effective methane recovery. The majority of the landfills (99.6%) in cities and towns with a population over 200 thousand included in the survey seem to have sufficient amounts of methane for its recovery. The waste level has not reached 5 m in only two SWDSs in the town of Krivyj Rig.

It should be noted that not all landfill gas generated can be collected. Some of the gas generated in a landfill escapes through the cover of even the most tightly constructed collection system [3]. Usually new collection systems are 70-85% collection efficiency; an average of 75% is used here for the estimation of the potential for methane emission reductions in Ukrainian landfills.

Annex 3 shows the potential for GHG emission reductions due to landfill gas flaring and utilization. It should be noted that potential GHG emission reductions account for a small amount of nitrous oxide, which is generated in combustion of landfill gas (both in flaring and utilization). Also, the data for the town of Krivyj Rig in the Dnipropetrovsk region includes only one landfill where methane recovery is considered to be cost-effective (i.e. the waste layer is more than 5m).

The potential for GHG emission reductions in the solid waste sector of Ukraine due to methane flaring can potentially be about 4.5 million tonnes of CO_2-equivalent. Methane utilization can provide greater emissions reductions than flaring by 7.6%, or by 340 thousand tonnes of CO_2-e.

Conclusions

1. The results of the inventory show that 573 thousand tonnes of methane were released from solid waste disposal sites into the atmosphere in 2002, which equals to over 12 million tonnes CO_2-e.

2. Cities and towns with population over 200 thousand people account for 285 thousand tonnes of CH_4 emissions (6 million tonnes of CO_2-e), or about 50% of all methane emissions from SWDSs in Ukraine in 2002.

3. This work provides a methodology for the inventory of methane emissions from solid waste disposal sites, which is based on IPCC default methodology adapted for Ukrainian conditions with adjusted fractions of potentially degradable organic components in solid waste.

4. The methane inventory has been carried out based on several data sources. It has taken into account the Official Statistics presenting summarized data on waste disposal by administrative regions, and population numbers and a previously conducted survey giving detailed information on individual SWDSs in cities and towns with populations over 200 thousand people.

5. The results showed a discrepancy among the different data sources. After the analysis of these differences, input data have been selected for the inventory. For organic industrial wastes, only official statistics have been used. For municipal waste, both and official data have been taken into account, and values were selected for each region either from national statistics or survey, whichever is more.

6. The amount of municipal waste in the Donetsk region given in the official statistics contradicts the average waste generation rate (10,735 thousand tonnes, or 7.3 kg per person per day instead of 0.93). Therefore, an estimated value of waste disposal based on population has been used for this region.

7. The amount of solid waste accepted for the inventory is 7,162 thousand tonnes, of which 5,749 (or more than 80%) is municipal solid waste.

8. According to the survey results 55.7% of solid waste disposal sites in Ukraine are unmanaged deep, 43.9% are managed, and the rest are unmanaged shallow.

9. The potential for emission reductions in Ukraine's solid waste sector through methane recovery in cities and towns with population over 200 thousand is about 4.5 million tonnes of CO_2-equivalent. Methane utilization provides greater emissions reductions than flaring by 7.6%, or by 340 thousand tonnes of CO_2-e.

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Annex 1. Fractions of potentially degradable organic components in the solid waste disposed of to solid waste disposal sites in 2002, percent

Administrative Regions of Ukraine	1. Paper	2. Textile Materials	3. Leather Materials	**4. Municipal Solid Waste**	5. Husks of Grapes	6. Pomace	7. Fruit Stones	8. Boon of Bast Fiber	9. Bagasse	10. After-yeast Oil Distiller's Slop	11. Grain and Potato Distillers' slop	12. After-defecation Residue	13. Husks from Sunflower Seeds	14. Barleycorn	15. Wood Waste	16. Screenings
Crimea	0.016	0.001	0.030	95.228	0.488	0.000	0.000	0.000	0.000	0.000	0.000	0.022	0.016	0.001	0.030	95.228
Vinnitsia Region	0.000	0.005	0.000	26.514	0.000	1.978	0.000	0.000	3.545	62.643	0.696	1.650	0.000	0.005	0.000	26.514
Volyn Region	0.003	0.028	0.000	75.270	0.000	0.135	0.000	0.000	15.900	0.000	0.000	0.000	0.003	0.028	0.000	75.270
Dnipropetrovsk Region	0.184	0.003	0.000	94.297	0.000	0.013	0.000	0.000	0.000	0.000	0.000	1.277	0.184	0.003	0.000	94.297
Donetsk Region	0.001	0.002	0.002	98.736	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.070	0.001	0.002	0.002	98.736
Zhytomyr Region	0.030	0.071	0.022	74.559	0.000	0.000	0.000	0.000	0.000	2.234	0.000	0.000	0.030	0.071	0.022	74.559
Transcarpathian Region	0.365	0.043	0.036	69.596	0.040	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.365	0.043	0.036	69.596
Zaporizhzhia Region	0.048	0.005	0.000	95.350	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.653	0.048	0.005	0.000	95.350
Ivano-Frankivsk Region	0.027	0.001	1.659	51.138	0.000	0.630	0.000	0.000	2.168	0.000	0.000	0.000	0.027	0.001	1.659	51.138
Kyiv Region	0.002	0.005	0.100	43.075	0.000	0.000	0.000	0.011	2.141	17.790	0.771	0.015	0.002	0.005	0.100	43.075
Kirovograd Region	0.004	0.002	0.000	89.041	0.000	0.000	0.000	0.000	3.473	0.000	0.000	0.385	0.004	0.002	0.000	89.041
Lugansk Region	0.013	0.003	0.001	96.922	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.017	0.013	0.003	0.001	96.922
Lviv Region	0.001	0.002	0.000	77.449	0.000	0.000	0.000	0.001	10.367	0.000	5.994	0.228	0.001	0.002	0.000	77.449
Mykolaiv Region	0.002	0.028	0.224	77.459	0.293	0.000	0.000	0.000	15.133	0.000	0.000	0.000	0.002	0.028	0.224	77.459
Odesa Region	0.012	0.004	0.000	96.753	0.270	0.000	0.000	0.000	0.080	0.000	0.000	0.104	0.012	0.004	0.000	96.753
Poltava Region	0.001	0.000	0.006	89.275	0.000	0.007	0.009	0.000	1.321	0.021	0.269	0.242	0.001	0.000	0.006	89.275
Rivne Region	0.001	0.000	0.000	93.202	0.000	0.038	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	93.202
Sumy Region	0.000	0.023	0.115	46.188	0.000	0.000	0.000	0.000	0.006	48.381	0.000	0.094	0.000	0.023	0.115	46.188
Ternopil Region	0.001	0.030	0.000	30.829	0.000	1.847	0.000	0.000	8.643	8.025	50.130	0.000	0.001	0.030	0.000	30.829
Kharkiv Region	0.055	0.017	0.000	63.615	0.000	0.000	0.000	0.000	0.631	28.208	0.000	0.082	0.055	0.017	0.000	63.615
Kherson Region	0.001	0.025	0.017	96.577	0.000	0.000	0.019	0.000	0.000	0.000	0.000	0.092	0.001	0.025	0.017	96.577
Khmelnytsky Region	0.018	0.006	0.000	78.981	0.000	0.000	0.000	0.000	16.133	0.000	0.000	0.000	0.018	0.006	0.000	78.981
Cherkasy Region	0.148	0.010	0.000	59.621	0.000	0.000	0.000	0.000	4.368	21.518	0.000	0.417	0.148	0.010	0.000	59.621
Chernivtsi Region	0.011	0.024	0.008	82.356	0.000	0.000	0.000	0.000	0.321	0.014	0.000	0.044	0.011	0.024	0.008	82.356
Chernigiv Region	0.002	0.020	0.003	76.823	0.000	0.000	0.000	0.048	5.073	0.000	0.000	0.000	0.002	0.020	0.003	76.823
City of Kyiv	0.016	0.008	0.072	99.205	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.016	0.008	0.072	99.205
City of Sevastopol	0.010	0.001	0.000	99.199	0.517	0.000	0.000	0.000	0.000	0.207	0.000	0.000	0.010	0.001	0.000	99.199
UKRAINE	0.026	0.010	0.048	80.266	0.038	0.212	0.001	0.002	2.706	7.922	2.134	0.270	0.026	0.010	0.048	80.266

Annex 2. Amounts of solid waste disposed of to SWDSs in 2002 used in the inventory, Gg.

Administrative Regions of Ukraine	Paper	Textile Materials	Leather Materials	**Municipal Solid Waste**	Husks of Grapes	Pomace	Fruit Stones	Boon of Bast Fiber	Bagasse	After-yeast Oil Distiller's Slop	Grain and Potato Distillers' slop	After-defecation Residue	Husks from Sunflower Seeds	Barley-corn	Waste Wood	Screenings	Total
Crimea	0.02	0.00	0.04	128.25	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	3.21	2.47	134.68
Vinnitsia Region	0.00	0.02	0.00	125.00	0.00	9.33	0.00	0.00	16.71	295.33	3.28	0.00	7.78	0.00	8.85	5.00	471.45
Volyn Region	0.00	0.04	0.00	96.10	0.00	0.17	0.00	0.00	20.30	0.00	0.00	0.00	0.00	0.01	10.76	0.29	127.67
Dnipropetrovsk Region	0.73	0.01	0.00	373.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	5.05	0.00	9.08	7.51	395.56
Donetsk Region	0.02	0.02	0.03	1,373.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.98	0.00	11.46	4.67	1,391.18
Zhytomyr Region	0.05	0.13	0.04	132.55	0.00	0.00	0.00	0.00	0.00	3.97	0.00	0.00	0.00	0.00	37.99	3.05	177.78
Transcarpathian Region	0.27	0.03	0.03	52.00	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	22.27	0.04	74.72
Zaporizhzhia Region	0.16	0.02	0.00	324.40	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	2.22	0.00	0.76	12.65	340.23
Ivano-Frankivsk Region	0.03	0.00	2.07	63.70	0.00	0.79	0.00	0.00	2.70	0.00	0.00	0.00	0.00	0.00	55.27	0.01	124.57
Kyiv Region	0.00	0.01	0.11	46.00	0.00	0.00	0.00	0.01	2.29	19.00	0.82	0.00	0.02	0.00	32.35	6.19	106.79
Kirovograd Region	0.00	0.00	0.00	75.92	0.00	0.00	0.00	0.00	2.96	0.00	0.00	0.00	0.33	0.00	1.99	3.97	85.27
Lugansk Region	0.04	0.01	0.00	299.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	2.07	7.23	309.12
Lviv Region	0.00	0.01	0.00	230.00	0.00	0.00	0.00	0.00	30.79	0.00	17.80	0.00	0.68	0.00	17.54	0.16	296.97
Mykolaiv Region	0.00	0.06	0.44	152.60	0.58	0.00	0.00	0.00	29.81	0.00	0.00	0.00	0.00	0.00	0.28	13.24	197.01
Odesa Region	0.04	0.01	0.00	319.18	0.89	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.34	0.00	1.19	7.95	329.89
Poltava Region	0.00	0.00	0.02	291.35	0.00	0.02	0.03	0.00	4.31	0.07	0.88	0.00	0.79	0.00	14.97	13.58	326.35
Rivne Region	0.00	0.00	0.00	97.40	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.10	0.97	104.51
Sumy Region	0.00	0.06	0.27	109.25	0.00	0.00	0.00	0.00	0.02	114.44	0.00	0.00	0.22	0.01	10.42	1.64	236.54
Ternopil Region	0.00	0.08	0.00	80.00	0.00	4.79	0.00	0.00	22.43	20.83	130.09	0.00	0.00	0.00	0.26	1.03	259.49
Kharkiv Region	0.17	0.06	0.00	200.00	0.00	0.00	0.00	0.00	1.98	88.68	0.00	0.00	0.26	0.00	9.35	13.85	314.39
Kherson Region	0.00	0.02	0.02	94.20	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.09	0.00	1.40	1.79	97.54
Khmelnytsky Region	0.05	0.02	0.00	213.90	0.00	0.00	0.00	0.00	43.69	0.00	0.00	0.00	0.00	0.00	1.70	11.47	270.83
Cherkasy Region	0.17	0.01	0.00	68.83	0.00	0.00	0.00	0.00	5.04	24.84	0.00	0.00	0.48	0.00	13.25	2.82	115.44
Chernivtsi Region	0.01	0.03	0.01	101.49	0.00	0.00	0.00	0.00	0.40	0.02	0.00	0.00	0.05	0.00	20.05	1.17	123.23
Chernigiv Region	0.00	0.04	0.01	153.00	0.00	0.00	0.00	0.10	10.10	0.00	0.00	0.00	0.00	0.00	30.28	2.43	199.16
City of Kyiv	0.07	0.04	0.32	439.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.84	0.26	443.21
City of Sevastopol	0.01	0.00	0.00	108.00	0.56	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.05	0.02	108.87
UKRAINE	1.89	0.71	3.40	5749.00	2.72	15.20	0.05	0.11	193.80	567.40	152.87	0.00	19.37	0.01	325.73	125.44	7,162.42

Annex 3. Assessment of potential for GHG emissions reductions due to landfill gas flaring and utilization, by towns and cities of Ukraine, 2002, Gg of CO_2-e.

Administrative Regions of Ukraine	CH_4 Emissions From SWDSs	Potential for GHG emission reductions in methane flaring	Potential for GHG emission reductions in methane utilization
Crimea	169.22	126.90	136.58
Vinnitsia Region	146.61	109.94	118.33
Volyn Region	107.21	80.39	86.53
Dnipropetrovsk Region	446.12	327.07	352.04
Donetsk Region	1,133.96	850.34	915.25
Zhytomyr Region	109.96	82.46	88.75
Transcarpathian Region	76.24	57.17	61.53
Zaporizhzhia Region	310.81	233.07	250.86
Ivano-Frankivsk Region	93.38	70.02	75.37
Kyiv Region	50.58	37.93	40.82
Kirovograd Region	71.25	53.43	57.51
Lugansk Region	103.94	77.94	83.89
Lviv Region	286.62	214.93	231.34
Mykolaiv Region	265.67	199.22	214.43
Odesa Region	384.85	288.59	310.62
Poltava Region	380.40	285.26	307.03
Rivne Region	140.74	105.54	113.60
Sumy Region	123.37	92.51	99.58
Ternopil Region	137.81	103.34	111.23
Kharkiv Region	329.87	247.37	266.25
Kherson Region	107.72	80.78	86.95
Khmelnytsky Region	117.29	87.95	94.67
Cherkasy Region	23.19	17.39	18.71
Chernivtsi Region	49.54	37.15	39.98
Chernigiv Region	146.61	109.94	118.33
City of Kyiv	466.96	350.17	376.89
City of Sevastopol	197.53	148.12	159.43
UKRAINE	5,977.41	4,474.94	4,816.51