ISSN 2224-4980

International Journal of Ecosystems and Ecology Science (IJEES)

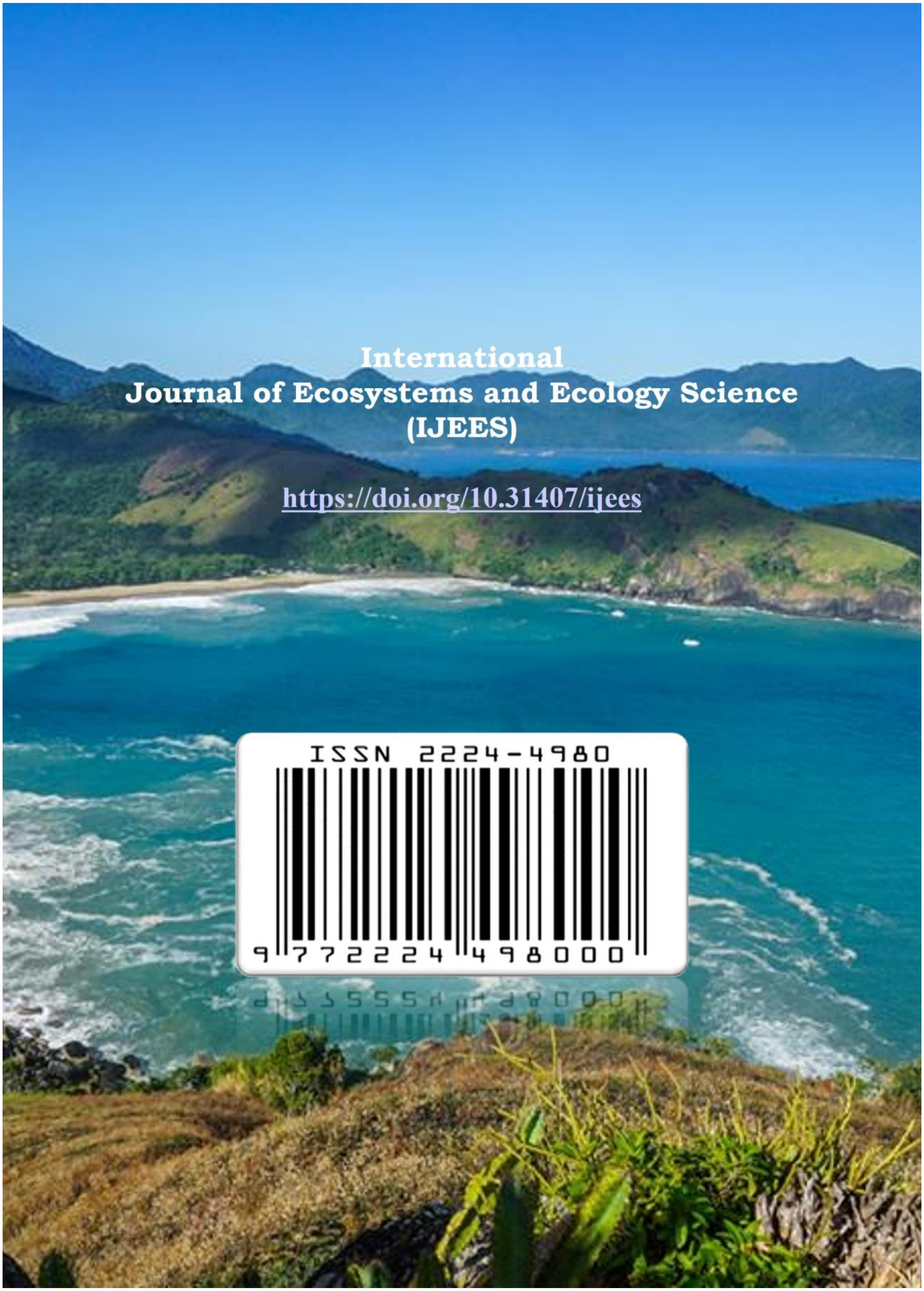
https://doi.org/10.31407/ijees

Essays on Ecosystems and Environmental Research

Volume 13/2, 2023

February 2023- June 2023

http://ijees.net/


International
Journal of Ecosystems and Ecology Science
(IJEES)
https://doi.org/10.31407/ijees
ISSN 2224-4980
9 772224 498000

International Journal of Ecosystems and Ecology Science (IJEES), ISSN: 2224-4980

Web of Science Group

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Volume 13, Issue 2, February 2023 - June 2023, (Serial Number 50)

Publication Information:

International journal of ecosystems and ecology science (IJEES), ISSN 2224-4980, publishing original articles, reviews and short communications of high scientific standard on ecosystems and science ecology. By: Hysen Mankolli, Professor, Ecologist, Plainfield, Illinois, USA; Health and Environment Association, Tirana, Albania;
ISSN International Centre, *Bibliographic Data Section*, PARIS, FRANCE;
Bib - ID 68337; ISO standard 3297;
Key title: International journal of ecosystems and ecology science
Abbreviated key title: *Int. j. ecosyst. ecol. sci.*
ISSN 2224-4980; **http://ijees.net/**
Frequency: four times a year. IJEES Electronic Journal Publication: Plainfield, Illinois, USA;
DOI prefix: 10.31407, **https://doi.org/10.31407/ijees**

Clarivate Analytics
https://rdmusm.files.wordpress.com/2020/01/journal-list-emerging-sources-citation-index-web-of-science-update-on-23-jan-2020.pdf
Web of Science Core Collection,
Journal Citation Indicator (JCI): 2020: 0.05; 2019:0.05
https://apps.clarivate.com/mjl-beta/search-results
Emerging Sources Citation Index - JOURNAL LIST
http://mjl.clarivate.com/cgi-bin/jrnlst/jlresults.cgi?PC=EX&Alpha=I
ESCI Clarivate,
https://rdmusm.files.wordpress.com/2020/01/journal-list-emerging-sources-citation-index-web-of-science-update-on-23-jan-2020.pdf
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DPI Digital Library USA and assign unique digital no. DPI: 16.10047.IJEES
U.S. National Library of Medicine,
NLM ID: 101726509 [Serial]; **Other ID:** (OCoLC)879805056;
https://www.ncbi.nlm.nih.gov/nlmcatalog/101726509

This journal has the status of an international journal.

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Abstracted / Indexed / Impact Factor in:

International journal of ecosystems and ecology science (IJEES), ISSN 2224-4980,

IJEES: http://ijees.net/
*IJEES have an international status and has been indexed, **abstracted, and have impact factors:***

ISSN Center responsible of the record: CIEPS - ISSN
https://portal.issn.org/resource/ISSN/2224-4980
IJEES doi crossref
https://doi.org/10.31407/ijees
IJEES, Volume 13/2 2023
https://ijees.net/journal-89-International-Journal-of-Ecosystems-and-Ecology-Science-(IJEES)-Volume-13-2,-2023.html
Web of Science Master List
https://rdmusm.files.wordpress.com/2020/01/journal-list-emerging-sources-citation-index-web-of-science-update-on-23-jan-2020.pdf
Journal Citation Report™ (JCR), Journal Citation Indicator (JCI):2021: 0.04; 2020:0.05
https://clarivate.com/webofsciencegroup/solutions/journal-citation-reports/
Emerging Sources Citation Index - JOURNAL LIST
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CiteFactor: IF 2019-2020:1.40;
https://www.citefactor.org/impact-factor/impact-factor-of-journal-International-Journal-of-Ecosystems-and-Ecology-Science-IJEES.php
EBSCO's library products,USA
http://www.ebscohost.com/for-publishers/for-publishers
IARC: Journal Impact Factor (USA), IF=2017**: 1.811; IF=**2016: **1.463;** =2015: **0.861**
http://iarcif.org/index.php/journal_information/show/44/0/2224-4980
Index Copernicus ICV= 2021: **100.00; ICV=** 2020: **100.00; ICV=** 2019: **100.00;**
https://journals.indexcopernicus.com/search/journal/issue?issueId=197247&journalId=31407
Academic Resource Index Research Bible:
http://paper.researchbib.com/view/issn/2224-4980/10/2
Scientific Journal Impact Factor Value 2020: SJIF 2020 = 7.167
http://sjifactor.com/masterlist.php?area=all&country=al&ord=sjif
Google scholar Cited: h-index: 10; Citations 400;
https://scholar.google.com/citations?user=W89N8qgAAAAJ&hl=en
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US. National Library of Medicine, NLM ID: 101726509 [Serial]; **Other ID:** (OCoLC)879805056;
https://www.ncbi.nlm.nih.gov/nlmcatalog/101726509
Global Impact Factor (GIF) IF: 2015: **0.765;** 2014: **0.625;** 2013: **0.541; IF=** 2012: **0.425**;
http://globalimpactfactor.com/journals-list/?snap=I
CAS Chemical Abstracts Service – CAS database
http://cassi.cas.org/search.jsp
Journal Factor: ISSN 2224-4980
http://www.journalfactor.org/advance_search.php
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IJEES Electronic Journal Publication: Plainfield, Illinois, USA; E-mail: editorijees@gmail.com;
Health and Environment Association, Tirana, Albania; E-mail: mjedisishendeti@yahoo.com;

International Journal of Ecosystems and Ecology Science (IJEES) **Vol. 13 (2):** 97-108 (2023)
https://doi.org/10.31407/ijees https://doi.org/10.31407/ijees13.2

TECHNOLOGICAL CHARACTERISTICS AND POTENTIAL OF LANDFILL BIOGAS FOR ELECTRICITY GENERATION

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Received January 2023; Accepted February 2023; Published March 2023;

DOI: https://doi.org/10.31407/ijees13.213

ABSTRACT

Climate change, which is observed on our planet at an unprecedented rate over the past decades or even millennia, is one of the most influential risks that determine the global development of mankind. Changes in the climate system pose serious threats and challenges to the sustainable development of society, caused by increased risks to human health and life, natural ecosystems, economic sectors and require detailed research and development of adaptation measures. Waste is one of the biggest problems of mankind today. Waste accompanies a person at every stage of his activity and requires a close approach to the issue of their disposal – burial at special landfills. This solution is not optimal, because it requires the annual alienation of land for the expansion of landfills and construction, and investments in these landfills, which must meet all technical and hygienic requirements. However, even landfills that meet all the established requirements cannot guarantee environmental safety. The landfill for waste disposal is a kind of biogas generator (landfill biogas), which is formed as a result of the decomposition of the organic waste fraction. This work is devoted to the analysis of modern designs for the collection and removal of landfill biogas, mathematical models for assessing the level of methane formation of solid waste landfills, the potential and prospects for the development of biogas power plants to reduce greenhouse gas emissions. A rational solution to these problems is the use of renewable energy sources, including biogas, the gas emitted by production and consumption waste in landfills of such waste. A prospective analysis of the volume of biogas was carried out on the example of a landfill for municipal solid waste in the city of Kamianets-Podilskyi, Khmelnytsky region (Ukraine).

Keywords: renewable sources of energy, power, biogas, biogas power plant, landfill, CO2 emissions, methane.

INTRODUCTION

Since the beginning of the 20th century, the anthropogenic factor has been providing a powerful, growing influence on the elements of the environment. Along with pollution of the natural environment and a decrease in the number of biological species, there is an intensive redistribution of matter and energy, which is not associated with natural biochemical cycles. The fundamental difference between the environment of agglomeration settlements and the natural environment is a broken circulation of substances, which in the process of technogenesis leads to serious violations of the biospheric balance. The most dangerous intervention of technogenesis in the biospheric carbon exchange (Akimova, Khaskin 2000). A significant anthropogenic factor of human activity on the cycles of biophilic elements is the formation of household waste and its destruction or disposal. The volumes of municipal solid waste (MSW) generation have reached geological scales, and the flows of a number of chemical elements are in one way or another associated with waste storage, which affects the global cycles of elements in the biosphere (Witkowska, 2010). The world volume of municipal solid waste accumulates about 1 billion m^3 per year (Bishkin, 2007). In most countries, a significant amount of MSW continues to be taken to landfills (landfills). The consequence of the formation, burial and incineration of organic waste is the irretrievable exclusion from the natural biological cycle of a large amount of organic and mineral substances. One of the main problems associated with waste disposal is the generation of biogas. The thickness of the waste layer, which consists of 50-60% of organic components, reaches several tens of meters. In the lower horizons of such deposits, anaerobic bacteria decompose organic matter with the formation of a gas mixture that contains: methane – 45-85%, carbon dioxide – 15-40%, as well as a small amount of nitrogen, oxygen, hydrogen, hydrogen sulfide and sulfur dioxide. The resulting mixture of gases is explosive and toxic. In the process of heat treatment or ignition of waste, carcinogenic compounds are released – benzene, benzopyrene and others. The emission of landfill gases that enter the environment causes negative effects of both local and global geoecological nature.

The modern MSW landfill is a large geotechnical ecosystem. Its main production facility is a geological scale solid phase anaerobic fermenter. Therefore, solid waste landfills are an important object of research aimed at using waste as industrial raw materials.

MATERIALS AND METHODS

The raw materials for the production of methane-containing gas are: organic waste: manure, grain and millet post-alcohol stillage, brewer grains, beet pulp, fecal sludge, fish and slaughterhouse waste (blood, fat, intestines, canygas), grass, household waste, dairy plant waste – lactose, whey, waste from biodiesel production – technical glycerin from the production of biodiesel from rapeseed, waste from juice production – fruit pulp, berry, grape pomace, algae, waste from the production of starch and molasses – pulp and syrup, waste from potato processing, from the production of chips – cleaning, skins, rotten tubers. Every year in Ukraine, 2 million tons of standard fuel are used for energy production. At the same time, the main contribution is made by wood – about 80% of the total amount of biomass. The energy potential of cereal straw and rapeseed is used least actively (Ovcharuk O., 2018, Ovcharuk O., 2020). The solid waste landfill is a special facility designed for the isolation and neutralization of solid waste. Landfills must guarantee the sanitary and epidemiological safety of the population. At the landfills, the static stability of MSW is ensured, taking into account the dynamics of compaction, salinity, gas release, the maximum load per unit area, the possibility of subsequent rational use of the site after the closure of the landfills (reclamation).
The disposal of municipal solid waste occurs as follows. First, a pit is dug out, which is covered from the inside with materials that prevent the penetration of toxic substances into the ground. To do this, the pit is covered with bentonite cloth or clay. Next, a drainage system is laid out on the bentonite fabric, which collects and removes all the accumulated liquid. The floor of the drainage system is laid with a layer of gravel, which prevents debris from clogging the pipes. Then the garbage is laid in layers. A layer of debris followed by a layer of sand, which prevents fires in the summer, and so on several layers. Wells are also being drilled at the landfill, into which pipes are placed to collect landfill gas or biogas. MSW consists of 70-80% organic components, most of which are subject to decomposition in time under burial conditions as a result of natural chemical and biological processes. The biochemical process of decomposition of the organic part of the waste by microorganisms is called fermentation. The fermentation process can take place under aerobic conditions (aerobic fermentation) or under anaerobic conditions (anaerobic fermentation). Thanks to biochemical reactions occurring in the body of the landfill: solid waste is biodegradable (food and vegetable residues, paper, fibrous materials of plant and animal origin), become biologically stable and is not a potential source of environmental pollution. Part of the solid waste containing carbon and protein passes into a gaseous state, as a result, the mass and volume of biosoluble solid organic waste are significantly reduced. Since waste is stored and stored at the landfill for a long time, the landfill ecosystem is dynamic, that is, it changes over time. As a result of the hydrolysis reaction, low molecular weight organic substances are formed, which pass the stage of oxygen-nitrate oxidation within several weeks and decompose under aerobic conditions to water, carbon dioxide and nitrogen.

During the course of these processes, an increase in temperature is noted in the body of the landfill. Anaerobic conditions are characterized by the stage of decomposition of hydrolysis products. In this case, two phases (stages) can be distinguished - phase I (acidic) and phase II (methanogenic). Biogas is the fuel of the future that can solve several environmental and oil depletion problems. Since a large amount of municipal solid waste is generated in the world and more landfills are being built for storing solid waste, the production and collection of biogas at landfills is a source of additional profit. Biogas solves the problem of biosoluble waste disposal. The composition of the resulting biogas depends on the substrate used and the processing method. This gas is not inferior to natural gas in its properties, it also solves the problem in the energy sector. The composition of biogas from the landfill for municipal solid waste is presented in Table 1.

Table 1. Typical biogas composition, %

Type	Brief characteristics of biogas	CH_4	CO_2	O_2	N_2
1	Pure biogas produced under anaerobic conditions	55	45	-	-
2	Biogas contains oxygen and nitrogen in the ratio characteristic of atmospheric air	40	30	6	24
3	Biogas used in the microbiological process (oxygen comes from landfill surface)	45	35	1	18
4	Combination of biogas types (2+3)	35	30	5	30

Favorable conditions for the accumulation of methane in landfills are created due to waste compaction, humidity, acidity, chemical composition, temperature from 50°C to 60°C, but can be formed at temperatures from 10°C to 60°C, pH 6.8-7,2. To quantify the potential of landfill gas for the conversion of carbon into methane contained in the waste from the solid domestic waste landfill in Kamenets-Podolsky (Ukraine) (Fig. 1), we use the mass balance method and the first-order decay (decomposition) method, which are based on one model – anaerobic destruction of organic matter with the formation of the corresponding decomposition products.

Figure 1. Municipal solid waste landfill and operating biogas combustion plant
(Kamianets-Podolsky, Ukraine, 2022)

Based on the first order damping method developed the most used models are:
1) IPCC model proposed by the Intergovernmental Panel on Climate Change (IPCC) (Guidelines, 2006);
2) the LandGEM model (Landfill Emission Gas Model – LandGEM) developed by the US Environmental Protection Agency (U.S. Environmental Protection Agency – U.S. EPA) (Landfill Gas, 2005).
IPCC model. The amount of methane Q(T), which is formed in a year T, is calculated by formula (1.1):

$$Q(T) = DDOC_{mT} \cdot F \cdot 16/12, \qquad (0.1)$$

where F is the proportion of methane in the total mass of biogas produced; DDOCm is the total mass of carbon biodegraded per year T, t, which is found from equation (1.2):

$$DDOC_{mT} = DDOC_{mdT} + DDOC_{maT-1}(1-e^{-k}), \qquad (0.2)$$

where, $DDOC_{maT-1}$ *– mass of carbon accumulated by the end of the year (T^{-1}), t;*

$DDOC_{mdT}$ *– mass of carbon removed to dumps and landfills during the period T, t;*
k – expansion constant, year $^{-1}$.

The mass of biodegradable carbon in the waste is found from the equation (1.3):

$$DDOC_m = W \cdot DOC \cdot DOC_f \cdot MCF, \qquad (0.3)$$

where, W – the total mass of waste disposed of in a landfill or landfill, t;
DOC – decomposable organic carbon per year of removal, t;
$_T CH_4, {}_T TBO^{-1}, DOC_f$ *– part of the carbon that takes part in the decomposition reactions;*
MCF *– correction factor for methane.*

Methane emissions from waste disposal sites ($Q(T)^{em}$) calculated as follows:

$$Q(T)^{em} = [Q(T) - R_T] \times (1 - OX_T], \qquad (0.4)$$

where, R_T *– mass of collected (recovered) methane, t;*
OX_T *– methane oxidation factor.*

For the convenience of calculating methane emissions using the IPCC model, a tool based on MS Excel spreadsheets – IPCC Waste Model.xls has been developed, which allows you to carry out various options for calculating methane emissions as a result of the decomposition of certain components of MSW and even part of industrial waste.

Landgem model. The LandGEM methane emissions model, developed by the US Environmental Protection Agency, is also based on a first-order decomposition (damping) equation. Thus, methane emissions from MSW disposal sites Q_{CH4} is described by the following equation:

$$Q_{CH4} = \sum_{x=1}^{n} \sum_{y=0.1}^{1} k \cdot L_0 (\frac{M_x}{10}) e^{-kt}, \qquad (0.5)$$

where n – the difference between the estimated year and the year of commencement of MSW disposal;
x and y – time steps equal to 1 and 0.1 years, respectively;
k – methane generation factor, year $^{-1}$*;*
L_0 *– methane formation potential, CH4, MSW* $^{-1}$ *(t);*
Mx – mass of MSW buried in year x, t year $^{-1}$*;*
t_{xy} *– age of the y-th part of the mass of waste buried in year x.*
Equation (6) for calculating biogas emissions (QLFG), adapted for Ukraine (Ukraine LFG Model), is as follows:

$$Q_{LFG} = \sum_{x=1}^{n} \sum_{y=0.1}^{1} 2k \cdot L_0 (\frac{M_x}{10}) e^{-kt_{xy}} \cdot MCF \cdot F_b, \qquad (0.6)$$

where MCF – correction factor of methane formation;
Fb is a correction factor for ignition, depends on the area and completeness of MSW burnout at the landfill, in proportion to which the biogas emission decreases.

RESULTS AND DISCUSSION

As is known, the destruction of biodegradable components of MSW in the places of their disposal for a long time (50-80 years) leads to the formation of the corresponding product - biogas, which consists of methane (40-60%), carbon dioxide (30-45%) and others. gases (5-10%). Biogas components that are greenhouse gases include: methane, carbon dioxide, non-methane volatile organic compounds and nitrous oxide. Methane emission is calculated by formula (1.4). The main source of carbon for the formation of methane are MSW components that contain bioavailable carbon: paper and cardboard, food and garden waste, wood, textiles, as well as leather, rubber and personal care products, isolated as separate components relatively recently. The index kj is one of the constants of the model, which determines the rate of waste decomposition and biogas production. kj is determined component by component and depends on factors such as humidity, waste pH, nutrient content and temperature partly on the climatic features of the territory where the MSW disposal site is located (Table 2).

Table 2. The value of the parameters of the constant rate of methane formation for various components of MSW at different levels of detail, kj, year^{-1}

№	Component	IPCC Model	Ukraine LFG Model	National Model	
1	Paper and cardboard	0,06	0,027	0,048	0,024
2	Textile				
3	Food waste	0,185	0,135	0,110	0,120
4	Wood	0,03	0,0135	0,024	0,012
5	Garden waste	0,1	0,068	0,07	0,06
6	Personal care products	0,1	-	0,048	0,120
7	Leather, rubber	-	0,0135	0,048	0,012
Average value for Ukraine		0,1296	0,0948	0,0829	-
		0,1127	0,0879	0,0875	

In the models under consideration, the type of MSW disposal site is taken into account through the MCF indicator. This indicator allows you to adjust the amount of methane generation, depending on the conditions of storage of solid waste at a landfill or landfill. Anaerobic landfills produce more methane than shallow landfills (Table 3).

Table 3. Indicator values MCF_i.

Types of landfills and landfills	*MCFi*
Controlled anaerobic	1,0
Controlled semi-anaerobic	0,5
Unmanaged deep	0,8
Unmanaged shallow	0,4
Unclassified	0,6
Average value for Ukraine	0,726

The value of MCFi=0.6 for unclassified landfills and landfills is recommended to be used by default in the absence of information on the distribution of disposal sites in the first four categories. As can be seen from Table. 2, the specification of this parameter for Ukraine improves the accuracy of calculations. The morphological composition of MSW is a determining factor in the formation of methane in waste disposal sites. It determines the mass of biodegradable carbon, which is transformed (at different rates) into methane and other greenhouse gases. Despite the commonality of the processes underlying the models, it is rather difficult to conduct a comparative analysis of the mathematical apparatus of the models in its original form. For example, the National and LandGEM models operate with the value L_0 – the potential for methane formation (though in different units of measurement), while the IPCC model (in the 2006 version) does not explicitly use such a value, although in (Guidelines ..., 2006) an equation for L_0 is given. Note that in the LandGEM model (including the adapted version) the parameter k is used as a factor, while in other models it is used as an exponent. In addition, in this model, the values of the parameters k and L0 do not depend on the morphological composition of MSW, and the same values of these parameters are assumed for the entire mass of waste.
Research on the use of models at the regional level is almost non-existent. Let's compare these models with the National model and consider the possibilities of application at the regional level. The IPCC model allows only methane emissions to be calculated. Carbon dioxide as a product of waste biodegradation in MSW disposal sites is considered in the «Agriculture…» sector. Nitrous oxide, due to small amounts, is not calculated (Guidelines..., 2006). The national model also allows only methane emissions to be calculated. Unlike them, the LandGEM model makes it possible to calculate the emission of not only methane, but also carbon dioxide and NVOCs, incl. for

specific substances. The value of carbon dioxide and NVOC emission depends on the results of methane emission calculation according to equation (5) (Landfill Gas…, 2005).

By the decision of the Paris Climate Agreement on December 12, 2015, to prevent the global average temperature from rising by more than 2°C (if possible, no more than 1.5°C) relative to the indicators before the start of the industrial revolution, when humanity began to burn a huge amount of fossil fuels, which led to a change climate. Keeping global warming at 1.5-2°C requires a rapid reduction in greenhouse gas emissions to the atmosphere to zero during the second half of the 21st century. This obliges the participating countries to minimize emissions of greenhouse gases such as methane and carbon dioxide into the atmosphere. As a result of anaerobic decomposition of the organic fraction of waste from the total amount of methane annually released into the atmosphere, 40-70% is formed as a result of anthropogenic activities, and more than 20% of them fall on solid waste disposal sites. The release of 1 m3 of methane into the atmosphere is equivalent to the release of about 25 m^3 of carbon dioxide into the atmosphere in terms of its detrimental consequences for climate change. Biogas is one of the causes of MSW fires in landfills and landfills. When the content in the air is from 5 to 15% methane and 12% oxygen, an explosive mixture is formed. International experience in the operation and reclamation of landfills shows that the only way to stop the release of biogas into the atmosphere is its organized removal through a system of wells and collectors with subsequent disposal and use in the national economy. The main method for solving this problem is the biogas collection and utilization scheme:

- creation of a network of vertical gas drainage wells connected by gas pipeline lines;
- depending on the number of wells at the landfill, collectors are installed to collect gas, pumping and compressor equipment for forced pumping of gas and its compression;
- installation of equipment for preliminary purification of biogas from siloxanes, hydrogen sulfide, carbon dioxide, harmful impurities and moisture for subsequent disposal.

In this regard, the reduction of biogas emissions into the atmosphere not only improves the environmental situation around solid waste landfills, but also contributes to the fulfillment of international obligations. When working with LandGEM Version 3.02 spreadsheets, we specified values of the parameters k = 0.075 $year^{-1}$, specific for the Khmelnytsky region (Table 1) and L_0 = 133 m^3 t LandGEM model, where the «weight» was the morphological composition of MSW in the Khmelnytsky region, the city of Kamenets-Podolsky. The period of the results of the calculation of biogas production is 80 years and was chosen according to the recommendations of foreign models. Forecast calculations of landfill gas and, in particular, methane are presented in Table 3, and graphs of gas generation volumes using this mathematical model are shown in Figures 2 and 3, respectively. The graph in Figure 3 shows that methane emissions will remain at a high level for at least another 20-25 years. Depending on the content of methane, biogas has a calorific value of 15 to 25 MJ/m^3 (3600-4800 kcal/m^3). The average calorific value of biogas is 4200 kcal/m^3. According to the heat of combustion, 1 m^3 of biogas is equivalent to: 0.8 m^3 of natural gas, 0.7 kg of fuel oil or 1.5 kg of firewood. As a result of calculations, the data in Table 3 indicate that the total gas emission of biogas from MSW in the forecast for 2022 is 3.5 million m^3/year, of which CH_4 is about 2.08 million m^3/year.

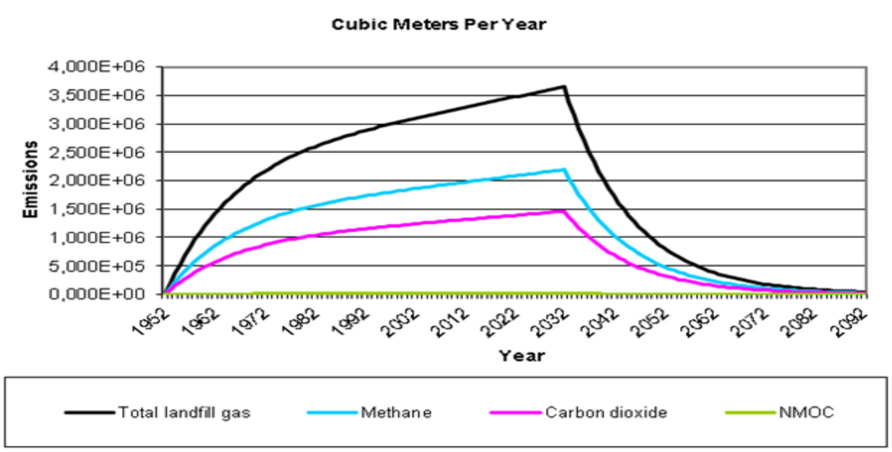

Figure 2. Graph of the calculation results of greenhouse gas emissions from the solid waste landfill in the city of Kamenets-Podolsky for the calculation period 1952-2032.

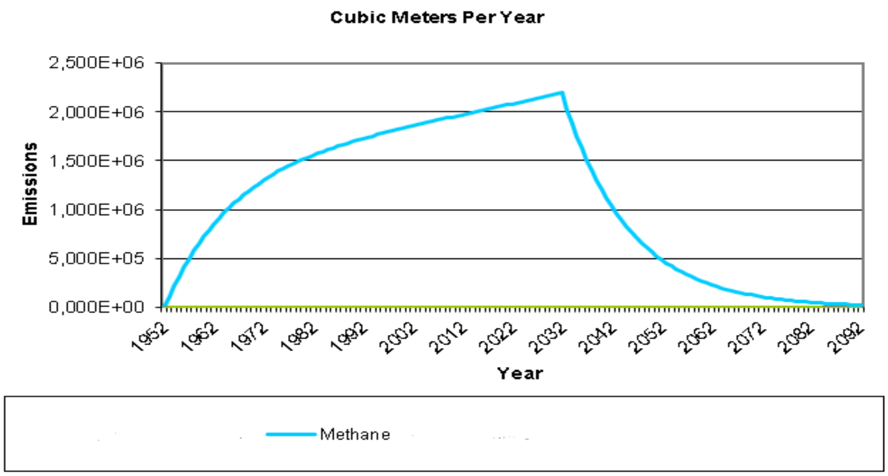

Figure 3. Graph of the results of calculating the methane emission from the solid waste landfill in the city of Kamenets-Podolsky for the calculation period 1952-2082.

As a result of calculations, the data in Table 3 indicate that the total gas emission of biogas from MSW in the forecast for 2022 is 3.5 million m3/year, of which CH4 is about 2.08 million m3/year.
Based on this, the estimated energy potential of this landfill is about 87.5×106 MJ/year. (based on the forecast for 2022).

Table 4. The results of the calculation of methane and other greenhouse gases emissions from 2021-2034 (Model LandGEM)

Year	Total landfill gas			Methane		
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
2021	4,539E+03	3,450E+06	2, 8E+02	1,381E+03	2,070E+06	1,391E+02
2022	4,563E+03	3,469E+06	2,331E+02	1,388E+03	2,081E+06	1,398E+02
2023	4,587E+03	3,487E+06	2,343E+02	1,396E+03	2,092E+06	1,406E+02
2024	4,611E+03	3,505E+06	2,355E+02	1,403E+03	2,103E+06	1,413E+02
2025	4,636E+03	3,524E+06	2,368E+02	1,411E+03	2,114E+06	1,421E+02
2026	4,660E+03	3,542E+06	2,380E+02	1,418E+03	2,125E+06	1,428E+02
2027	4,684E+03	3,561E+06	2,392E+02	1,425E+03	2,136E+06	1,435E+02
2028	4,708E+03	3,579E+06	2,405E+02	1,433E+03	2,147E+06	1,443E+02
2029	4,733E+03	3,598E+06	2,417E+02	1,440E+03	2,159E+06	1,450E+02
2030	4,757E+03	3,616E+06	2,430E+02	1,448E+03	2,170E+06	1,458E+02
2031	4,782E+03	3,635E+06	2,442E+02	1,455E+03	2,181E+06	1,465E+02
2032	4,806E+03	3,654E+06	2,455E+02	1,462E+03	2,192E+06	1,473E+02
2033	4,459E+03	3,390E+06	2,277E+02	1,357E+03	2,034E+06	1,366E+02
2034	4,137E+03	3,145E+06	2,113E+02	1,259E+03	1,887E+06	1,268E+02

As we can see from the results, the application of calculation methods gives different results. Closer are the results obtained by the National model and the IPCC model. Especially in the case of using the updated value MCF = 0.63. Insignificant differences can be explained by the fact that in the first case such MSW components as leather and rubber are additionally taken into account. The results of the calculation according to the LandGEM model differ significantly from these results. The LandGEM model was developed on the basis of research conducted at American test sites. As noted in the paper, in relation to Ukrainian conditions, the LandGEM model gives rather overestimated results. The disadvantages of the original LandGEM model include the lack of consideration of the morphological composition of MSW when choosing the parameters k and L_0, although when working with the

LandGEM Version 3.02 spreadsheets, we used the values calculated for the Khmelnitsky region. A significant disadvantage of applying the adapted version of the LandGEM model to territorial units is the impossibility of determining the parameter F due to the lack of data on the scale and depth of waste burnout in individual landfills. Although the work (Pukhnyuk, 2011) suggests a value of F = 0.8 to provide a conservative assessment of the biogas potential of Ukrainian landfills. In the National and IPCC models, the actual burnout of a part of organic matter in the body of the landfill is not taken into account.

The advantages of the LandGEM Version 3.02 tool include the ability to calculate emissions of biogas and GHGs other than methane. However, such results can be obtained as derivatives of the results of calculations by other methods, based on the ratio between the biogas components. The LandGEM model in its original and adapted versions is suitable for use in a specific MSW disposal site.

As noted above, all models are based on a differential equation for the reaction of decomposition of organic matter in the body of the landfill, but differences in the values of individual parameters and in the mathematical apparatus of the models lead to discrepancies in the results.

Since the main method of handling municipal solid waste is (and remains in the future) disposal in landfills and landfills, the issues of assessing the impact of such facilities on the environment are relevant. One of such research areas is the assessment of greenhouse gas emissions. The article considered the most used models (methods) for determining greenhouse gas emissions from municipal solid waste disposal sites – IPCC and LandGEM models, as well as the National Gas Generation Model (Ukraine). A comparative analysis of the models made it possible to determine their advantages, disadvantages, as well as the possibility of mutual replacement of model parameters. Models can be used both for a specific waste disposal site and for territories of various levels of organization. The parameters that are specified depending on the object of study include: the morphological composition of municipal solid waste, climatic conditions and features of burial sites. To improve the accuracy of calculations, it is recommended to take into account the maximum number of household waste components (7 components), which are a source of bioavailable carbon. The rate of decomposition of individual waste components is most accurately displayed in the developed sets of values of the parameter k from the version of the LandGEM model adapted to Ukrainian conditions. Approximation of the parameter values to the regional and national levels is recommended to be carried out on the basis of the climatic zoning of the territory.

The parameters of the models that are considered in the article are usually interchangeable and can be refined to the level of a particular polygon.

Discussion

The nature and intensity of microbiological processes in landfills allows us to consider them as powerful artificial systems from the production of biogas (Minko, Lifshits, 1992). Every year, 30-70 million tons of biogas are released into the atmosphere from the landfills of the globe (Fedorova, Prokhorova, 1997). The rate of gas emission from the surface of the MSW landfill into the atmosphere is n10 – n100 times higher than the known values of the intensity of gas flows from natural ecosystems (Safranov et al., 2016).

In the study of the gas component of landfills, more than 100 components were found. The presence of heavy (including aromatic) hydrocarbons, chlorinated hydrocarbons, alcohols, ethers and other volatile organic substances in biogas has been established. It is assumed that the main part of hydrocarbons and chlorinated hydrocarbons is of non-biological origin, and their presence in biogas is the result of evaporation of various types of fuel and solvents and chemical reactions occurring in the landfill body (destruction of rubber products and other synthetic materials). Landfill gas is a unique gas mixture in terms of its component composition, which has no analogues among gas mixtures formed by natural bio-inert and geological bodies. In this regard, a direct consequence of the presence of a large landfill will be the occurrence of anomalies in the atmosphere adjacent to it, both in terms of the quantitative content and the qualitative composition of volatile organic compounds (Minko et al., 1990; Minko, Lifshits, 1992; Mazur, V. et al., 2021).

Ecotoxicants may also migrate from landfills as part of dust and aerosol flares.

Estimates show (Abramov, 1994) that the amount of biogas generated depends on the content of the organic fraction (food waste, paper, wood). The highest concentration of methane in biogas (60% or more) gives the process of decomposition of food waste. Organic substances contained in the wast

e are divided into three classes, each of which corresponds to a certain output of methane: carbohydrates – 0.42-0.47 m^3 / kg, proteins – 0.45-0.55 m^3 / kg, fats – up to 1 m^3/kg (Fedorov, 2002).

Anaerobic decomposition of MSW with the release of biogas begins 180–500 days after waste disposal (Abramov, 1994; Ignatovich, Rybalsky, 1998) . According to N.F. Abramov (1994), up to 250 m^3 of biogas is formed from each ton of waste. According to some estimates (Dieter, 1977), 1 ton of MSW containing 200 kg of organic matter yields

100 m^3 of methane. The stage of methanogenesis is divided into the active phase (10-30 years) with high rates of methane release and the stable phase (up to 100 years or more).

In the active phase, the enzymatic decomposition of acids formed in the acetogenic phase proceeds, while the methane content in biogas gradually increases and reaches 50–60% (Maksimova et al., 2003). During this period, industrial production and utilization of biogas is possible (Abramov, 1994; Ignatovich, Rybalsky, 1998 (1)). In the stable phase, there is a slow degradation of cellulose, as well as hardly decomposable waste fractions – lignin, some types of plastics. The rate and volume of methane emission in this phase decrease (Maximova et al., 2003). Some authors argue that the release of gases from the landfill lasts at least 75 years (Skorik et al., 1998). Over 30-50 years, approximately 30% of the buried organic matter is transformed, the rest continues to decompose over the next decades (Vavilin et al., 2003).

The resulting biogas migrates up the section and is oxidized in the surface layers under aerobic conditions, while non-oxidized components and oxidation products can be released into the atmosphere. Due to the existence of an oxidizing biofilter, the top layer of soil (from 0 to 1 m) serves as a geochemical barrier to the path of atmospheric oxygen to the lower layers and biogas to the atmosphere (Lebedev et al., 1993).

V. A. Isidorov (2001) proves that MSW landfills make a significant contribution to the global methane flux. CH_4 release from landfills is estimated at 20-70 Mt/year, which is from 6 to 8% of the total methane release into the atmosphere from all sources. The role of methane in global processes is not limited to its direct participation in the absorption of the Earth's thermal radiation in the infrared region of the spectrum (the contribution of methane to the creation of the greenhouse effect is approximately 30% of the value assumed for carbon dioxide). Its content largely determines the oxidizing properties of the atmosphere and, thus, the fate of many other gas components, including greenhouse gases and pollutants.

In many countries of the world, solid waste landfills (landfills) are considered as giant bioreactors loaded with energy raw materials and capable of providing significant savings on traditional energy materials.

Utilization of biogas can improve the environment and reduce the risk of fires (Abramov, 1994; Vavilin et al., 2003).

Thus, the process of anaerobic decomposition of the organic fraction of MSW is the main factor in air pollution during waste disposal in landfills (landfills).

In European countries, laws have already been adopted to significantly reduce and prevent the flow of organic waste to landfills (Vavilin et al., 2003). According to the EU Regulation, all landfills with a volume of more than 10 thousand tons must be supplied with a biogas collection system (Vandrash, Sergeev, 1999).

Description of the solid waste landfill. With the current level of scientific and technological progress, energy consumption can only be covered by the use of fossil fuels (coal, oil, gas). However, according to the results of numerous studies, fossil fuels in the near future can only partially satisfy the demands of world energy. Another part of the energy demand can be met by other sources of energy – non-traditional and renewable.

Biogas is an alternative source of energy, its properties are not inferior to natural gas. To the undoubted advantages of biofuel obtained by means of waste processing is its availability. Recently, much attention has been given to hydrogen as an alternative fuel. But the cost of biogas production is much lower than the cost of hydrogen production. Another prospect of biogas is a rich, almost unlimited, restoring raw material base. The main way to use biogas is to turn it into a source of thermal, mechanical and electrical energy. However, large biogas plants can be used to create production facilities for the production of valuable chemical products for the national economy. Biogas can be used to generate energy that is used for heating, lighting, supply of feed preparation shops, for the operation of water heaters, gas stoves, infrared emitters. Biogas can also be used as a gas motor fuel.

Studies show that more organic waste is generated in the world from 20 to 50%. The least metal waste is formed from 0 to 8%. Also in cities, metal and glass form a minimum amount, more organic waste. Biogas consists of 55%-75% methane, 25%-45% CO_2, small amounts of H_2, NH_3 and H_2S. Biogas has a total energy of 44 kW. After purification of biogas from CO_2, biomethane is obtained. Biomethane is a complete analogue of natural gas. The only difference is in the origin.

CONCLUSIONS

- Ensuring the environmental safety of solid waste landfills is possible through their proper arrangement and operation. In addition to reducing damage to the natural environment, additional energy benefits are achieved from the collection and utilization of methane-containing gas.

- As we can see from the results, the application of calculation methods gives different results. Closer are the results obtained by the National model and the IPCC model. Especially in the case of using the updated value MCF = 0.63. Insignificant differences can be explained by the fact that in the first case such MSW components as leather and rubber are additionally taken into account. The results of the calculation according to the LandGEM model differ significantly from these results. The LandGEM model was developed on the basis of research conducted at American test sites. As applied to Ukrainian conditions, the LandGEM model gives rather overestimated results. The disadvantages of the original LandGEM model include the lack of consideration of the morphological composition of MSW when choosing the parameters k and L_0, although when working with the LandGEM Version 3.02 spreadsheets, we used the values calculated for the Khmelnitsky region. A significant disadvantage of applying the adapted version of the LandGEM model to territorial units is the impossibility of determining the parameter F due to the lack of data on the scale and depth of waste burnout in individual landfills. Although, in order to provide a conservative assessment of the biogas potential of Ukraine's landfills, a value of F=0.8 is proposed. In the National and IPCC models, the actual burnout of a part of organic matter in the body of the landfill is not taken into account.
- The advantages of the LandGEM Version 3.02 tool include the ability to calculate emissions of biogas and GHGs other than methane. However, such results can be obtained as derivatives of the results of calculations by other methods, based on the ratio between the biogas components. The LandGEM model in its original and adapted versions is suitable for use in a specific MSW disposal site.

REFERENCES

1. Bakhmat O.M. (2012). Modeliuvannia adaptyvnoi tekhnolohii vyroshchuvannia soi. Modeling adaptive technology of soybean cultivation Monohrafiia. Kamianets-Podilskyi: Vydavets: P. 15;
2. Bashkin VN Ecological risks: calculation, management, insurance: Proc. allowance, 2007. 360 p;
3. Bondarenko V., Havrylianchik R., Ovcharuk O., Pantsyreva H., Krusheknyckiy V., Tkach O. and Niemec M. Features of the soybean photosynthetic productivity indicators formation depending on the foliar nutrition. Ecology, Environment and Conservation. Vol. 28. Issue 2022. P. 20-26. DOI: 10.53550/EEC.2022.v28i04s.004;
4. DBN V.2.4-2-2005 Poligoni tverdikh pobutovikh vidkhodiv. Osnovni polozhennia proektuvannia [Landfills. The basic design provisions]. 2005. Ukraine state building Publ., 68 p;
5. Dieter H. Gestaltung und Rekultivierung von Deponien und ungeordneten Mullablagerungsplatzen in Bayern. Kommunalwirtschaft. 1977. №8. S. 252–256;
6. Honcharuk I., Matusyak M., Pantsyreva H., Kupchuk I., Prokopchuk V., Telekalo N. Peculiarities of reproduction of pinus nigra arn. in Ukraine. *Bulletin of the Transilvania University of Brasov, Series II: Forestry, Wood Industry, Agricultural Food Engineering*. 2022. Vol. 15 (64). № 1. P. 33-42. DOI: 10.31926/but.fwiafe.2022.15.64.1.3;
7. Honcharuk, I. et al. (2020). Efficiency of growing legumes crops in Ukraine. In :Integration of traditional and innovation processes of development of modern science: ñollective monograph (3rd ed). (Ed. A. Jankovska). Baltija Publishing, Riga, Latvia, 42– 65. DOI: 10.30525/978-9934-26-021- 6-31;
8. Isidorov V. A. Ecological chemistry: Textbook for universities. St. Petersburg: Himizdat, 2001. 303 p;
9. Issledovanija gazoobrazovanija na naibolee krupnyh poligonah TBO i perehod na trehkomponentnuju nacional'nuju model' raschetov vybrosov PG ot svalok TBO v Ukraine: otchet o NIR [The research of gas formation at the largest landfills and transition to a three-component national model for calculating GHG emissions from landfills in Ukraine: a report of research]. 2012. Kiev, Institute of Engineering Thermophysics Ukraine National Academy of Sciences Publ., 82 p;
10. Ivanyshyn O., Khomina V., Pantsyreva H. Influence of fertilization on the formation of grain productivity in different-maturing maize hybrids *Ukrainian Journal of Ecology*. 2021. 11 (3). P. 262-269. Doi: 10.15421/2021_170;
11. Kaletnik, G. et al. (2020). The The Waste-Free Production Development for the Energy Autonomy Formation of Ukrainian Agricultural Enterprises. Journal of Environmental Management and Tourismthis. 11(3): 513–522;

12. Kaletnik, G.M. (2010). Biofuels. Food, Energy and Environmental Security of Ukraine: Monograph. K: High-tech Press, 516;
13. Landfill Gas Emission Model (LandGEM) Ver. 3.02: User`s Guide. 2005. – U.S. EPA, Washington, U.S. EPA, 48 p. Available at: https://www3.epa.gov/ ttncatc1/dir1/landgem-v302-guide.pdf (accessed 14 April 2017);
14. Lebedev V. S., Gorbatyuk O. V., Ivanov D. V., Nozhevnikova A. N., Nekrasova V. K. Biogeochemical processes of formation and oxidation of biogas at domestic waste dumps. Journal of Ecological Chemistry. 1993. No. 4. S. 323–334;
15. Maksimova SV, Glushankova IS, Vaysman O. Ya. Modeling of biogas formation processes at solid domestic waste landfills Engineering ecology. 2003. No. 4. S. 32–40;
16. Mazur V., Pantsyreva H., Mazur K., Myalkovsky R., Alekseev O. Agroecological prospects of using corn hybrids for biogas production. *Agronomy Research.* 2020. Volume 18. P. 205-219;
17. Mazur, V. et al. (2021). Ecological suitability peas (Pisum sativum) varieties to climate change in Ukraine. Agraarteadus, 32 (2), 276–283. https://doi.org/10.15159/jas.21.26;
18. Mazur, V. et al. (2021). Ecological suitability peas (Pisum sativum) varieties to climate change in Ukraine. Agraarteadus, 32 (2), 276–283. https://doi.org/10.15159/jas.21.26;
19. Mazur, V. A. (2018). Primary introduction assessment of decorative species of the lupinus generation in Podillya. Scientific Bulletin of UNFU, 28(7), 40–43. https://doi.org/10.15421/40280708;
20. Mazur, V. A., Myalkovsky, R.O., Mazur, K. V., Pantsyreva, H. V., Alekseev, O.O. 2019 Influence of the Photosynthetic Productivity and Seed Productivity of White Lupine Plants. Ukrainian Journal of Ecology, 9(4), 665-670. DOI: 10.15421/2019_807;
21. Mazur, V., Didur, I., Myalkovsky, R., Pantsyreva, H., Telekalo, N., Tkach, O. (2020). The Productivity of intensive pea varieties depending on the seeds treatment and foliar fertilizing under conditions of right-bank forest-steppe Ukraine. Ukrainian Journal of Ecology, 10(1), 101-105.
22. Mazur, V.A., Branitskyi, Y.Y., Pantsyreva, H.V.(2020). Bioenergy and economic efficiency technological methods growing of switchgrass. Ukrainian Journal of Ecology, 10(2), 8-15;
23. Nacional'nyj Kadastr antropogennyh vybrosov iz istochnikov i absorbcii poglotiteljami parnikovyh gazov v Ukraine za 1990-2013 gg. [National Inventories of anthropogenic emissions from sources and removal by greenhouse gases absorbers in Ukraine in 1990-2013]. 2015. Kiev, 569 p. URL: http:// www.menr.gov.ua/docs/klimatychna-polityka/ UKR_NIR_2015_final.pdf (acces- sed 14 April 2017);
24. Nataliia Kovalenko, Taras Hutsol, Vitalii Kovalenko, Szymon Glowacki, Sergii Kokovikhin, Viktor Dubik, Oleksander Mudragel, Maciej Kuboń, Wioletta Tomaszewska-Górecka (2021). Hydrogen production analysis: prospects for Ukraine / Agricultural Engineering, Vol. 25, No. 1, pp. 99 -114. DOI: 10.2478/agriceng-2021-0008;
25. Ovcharuk, O., Hutsol, T., Ovcharuk, O. (2018) Ekolohichni tendentsii ta perspektyvy vykorystannia biomasy roslyn dlia vyrobnytstva alternatyvnoho palyva v Ukraini / Zbirnyk naukovykh prats mizhnarodnoi naukovo-praktychnoi konferentsii «Ahrarna nauka i osvita v umovakh yevrointehratsii», Vol. 1, Kamianets-Podilskyi, P. 29-32;
26. Ovcharuk, O.; Hutsol, T.; Ovcharuk, O.; Rudskyi, V.; Mudryk, K.; Jewiarz, M.; Wróbel, M.; Styks, J. (2020) Prospects of use of nutrient remains of corn plants on biofuels and production technology of pellets. In Renewable Energy Sources: Engineering, Technology, Innovation; Springer: Cham, Switzerland, 2020; pp. 293-300;
27. Pancyreva, G. V. (2016). Doslidzhennya sortovyx resursiv lyupynu bilogo (Lupinus albus L.) v Ukrayini, (Vol. 4, pp. 88–93);
28. Pantsyreva H., Mazur K. Research of early rating soybean varieties on technology and agroecological resistance. Theoretical and practical aspects of the development of modern scientific research: Scientific monograph. Part 2. Riga, Latvia: Baltija Publishing, 2022. P. 84-108. DOI: https://doi.org/10.30525/978-9934-26-195-4-18;
29. Pantsyreva H., Stroyanovskiy V., Mazur K., Chynchyk O., Myalkovsky R. The influence of bio-organic growing technology on the productivity of legumins. *Ukrainian Journal of Ecology.* 2021. 11 (3). P. 35-39. Doi: 10.15421/2021_139;
30. Pantsyreva, H.V. Morphological and ecological-biological evaluation of the decorative species of the genus Lupinus L. Ukrainian Journal of Ecology, 9(3), 74-77. 21997. https://doi.org/10.15421/2019_711;

31. Puhnjuk A. Ju. 2011. Issledovanie gazoobrazovanija na staryh ukrainskih poligonah tverdyh bytovyh othodov [Investigation of gas formation at old Ukrainian solid waste landfills]. 2011. Prom. teplotehnika – Industrial heat engeneereing, vol. 34 (no. 4), pp. 83-93;
32. Puyu V., Bakhmat M., Pantsyreva H., Khmelianchyshyn Y., Stepanchenko V., Bakhmat O. Social-and-Ecological Aspects of Forage Production Reform in Ukraine in the Early 21st Century. *European Journal of Sustainable Development* (2021). Vol. 10(1). P. 221-228;
33. Safranov T. A., Prihod'ko V. Ju., Shanina T. P. (2016) Problema rozmishchennia vidkhodiv na zvalishchakh ta poligonakh Odes'koï oblasti [The problem of waste disposal on landfills and dumps of the Odessa region]. Visnik Harkivs'kogo nacional'nogo universitetu im. V. N. Karazina Visnyk of V. N. Karazin Kharkiv national university, vol. 14, pp. 83-90;
34. Savelii KUKHARETS, Taras HUTSOL, Szymon GŁOWACKI, Olena SUKMANIUK, Anna ROZKOSZ, Oleg TKACH Concept of Biohydrogen Production by Agricultural Enterprises. Agricultural Engineering Vol. 25. No. 1. 2021. P. 63-72;
35. Shmarin S. L., Alekseevec I. L., Filozof R. S., Remez N. S., Denafas G. 2014. Soderzhanie biorazlagaemykh komponentov v sostave tverdykh bytovykh otkhodov v Ukraine. [The content of biodegradable components in municipal solid waste in Ukraine]. Jekologija i promyshlennost'. Ecology and industry, vol. 1, pp. 79-83;
36. Shmarin S.L., Slivinskaya V.V., Remez N.S., Filozof R.S., Nakhshina A.D., Mykhaylenko V.P. 2014. Vlijanie klimaticheskih faktorov na ocenku vybrosov parnikovyh gazov s mest zahoronenija tverdyh bytovyh othodov v Ukraine [Influence of climatic factors on estimation of greenhouse gas emissions from the burial place solid waste in Ukraine]. Fizichna geografija ta geomorfologija. Physical geography and geomorphology, vol. 2(79), pp. 133-140;
37. Ukraine Landfill Gas Model Ver.1.0: User’s Manual. 2009. – U.S. EPA; edited by Swapura Ganguli, G. Alex Stege, Washington, U.S. EPA Landfill Methane Outreach Program, 28 p. – Available at: https://www.globalmethane.org/ documents/toolsres_lfg_manual.pdf (accessed 14 April 2017);
38. Vavilin V. A., Lukoshina L. Ya., Nozhevnikova A. N., Kalyuzhny S. V. Landfill as an excitable environment. Priroda. 2003. No. 5. S. 54-60;
39. Vitkovskaya SE Entry of heavy metals into plants when using compost from municipal solid waste as an organic fertilizer. Agrochemistry. 2000. No. 5. S. 78–82;
40. Volynkina E. P., Domnin K. I. 2014. Matematicheskaja model' dlja prognoznyh raschetov obrazovanija i izvlechenija svalochnogo gaza na zakrytyh svalkah TBO [Mathematical model for forecast calculations of landfill gas formation and extraction in closed solid waste dumps]. Vestnik Sibirskogo gosudarstvennogo industrial'nogo universiteta – Bulletin of Siberian state industrial university, vol. 3(9), pp. 62-70;