APPROACHES TO ESTIMATING GREENHOUSE GAS EMISSIONS FROM THE BY-PRODUCTS OF LIVESTOCK FARMING IN UKRAINE

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Climate change due to human activity in developed countries leads to numerous cases of deterioration of living conditions in all regions of the planet. However, it is possible to change this situation. To do this, it is necessary to maintain the global temperature at today's level by reducing emissions of greenhouse gases into the atmosphere. Agriculture makes a significant contribution to anthropogenic global warming, particularly livestock. Animal manure and the soils cultivated with it are the most important sources of emissions from livestock after intestinal methane. Experts estimate that nitrous oxide and methane produced in pastures and manure processing systems can account for up to a quarter of on-farm emissions, so it is important to identify strategies to reduce the flow of these gases. To solve the problem of global warming, it is necessary to control a number of positions, one of which is the assessment of actual emissions of greenhouse gases and, in particular, in the production of livestock products.

The article presents a new approach to increasing the accuracy of greenhouse gas emissions calculations. To determine the gross energy in the methodology of effective practice, the values of the indicators of clean energy are used to maintain the needs of animals for the continuation of vital activities and taking into account their productivity. When expanding the approaches for obtaining raw data for determining greenhouse gas emissions from by-products of livestock farming to determine gross energy, use the indicators of the content of crude protein, crude fat, crude fiber, and non-nitrogenous extractives in the diet.

The yield of animal excrement is calculated based on the weight and composition of the feed, taking into account the digestibility of the organic matter of the feed and the relative content of organic matter.

When separating livestock by-products (organic waste) into solid and liquid fractions, the actual data characterizing the quality of separation on individual elements of the technological line are the mass and moisture content of effluents entering processing and obtained at the exit, the mass and moisture content of the liquid fraction, and the mass and moisture content of the solid fraction.

Key words: livestock by-products, nutrient digestibility, greenhouse gases, separation efficiency, liquid, solid fractions.

ПІДХОДИ ДО ОЦІНКИ ВИКИДІВ ПАРНИКОВИХ ГАЗІВ З ПОБІЧНОЇ ПРОДУКЦІЇ ТВАРИННИЦТВА В ГОСПОДАРСТВАХ УКРАЇНИ

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Зміна клімату через діяльність людини у розвинених країнах призводить до численних випадків погіршення умов мешкання у всіх регіонах планети. Проте є спроможність змінити цю ситуацію. Для цього необхідно утримати глобальну температуру на сьогоднішньому рівні за рахунок зниження викидів до атмосфери парникових газів. Сільське господарство робить значний внесок в антропогенне глобальне потепління, зокрема тваринництво. Гній тварин і оброблювані ним ґрунти є найважливішими джерелами викидів від худоби після кишкового метану. За експертними оцінками, закис азоту та метан, що утворюються на пасовищах і системах переробки гною, можуть складати до чверті викидів, що утворюються на фермі, і тому важливо визначити стратегії скорочення потоків цих газів. Для вирішення проблеми глобального потепління необхідно контролювати ряд позицій, однією із яких є оцінка фактичних викидів парникових газів і, зокрема, при виробництві тваринницької продукції.

У статті пропонується новий підхід до підвищення точності розрахунків викидів парникових газів. Для визначення валової енергії в методології ефективної практики використовуються значення показників чистої енергії на підтримання потреб тварин для продовження життєдіяльності та з урахуванням їх продуктивності. При розширенні підходів для отримання вихідних даних з визначення викидів парникових газів з побічної продукції тваринництва для визначення валової енергії використовувати основі показників вмісту сирого протеїну, сирого жиру, сирої клітковини, безазотистих екстрактивних речовин в раціоні.

Вихід екскрементів тварин розраховується за масою та складом кормів з урахуванням коефіцієнт перетравлення органічної речовини корму та відносний вміст органічної речовини.

При розділенні побічної продукції тваринництва (органічні відходи) на тверду і рідку фракції фактичні дані, що характеризують якість розділення на окремих елементах технологічної лінії – це маса і вологість стоків, що надходять на оброблення та отримані на виході, маса і вологість рідкої фракції та маса і вологість твердої фракції.

Ключові слова: побічна продукція тваринництва, перетравність поживних речовин, парникові гази, ефективність розділення, рідка, тверда фракції.

Introduction. Human activity has led to climate change, and, as a result, to numerous cases of worsening weather conditions in all regions of the planet, moreover, to the change of the entire climate system of the Earth, and these changes are reflected in the state of the atmosphere, ice caps, oceans and land. According to a report by the Intergovernmental Panel on Climate Change (IPCC), anthropogenic greenhouse gas

(GHG) emissions were the main cause of global climate warming of about 1.1 °C between 1850 and 1900. According to scientists' forecasts, this indicator may increase by another 1.5^0 C in the next 20 years. This leads to the melting of glaciers and, as a result, to a rise in the level of the world ocean.

Similar data regarding Great Britain are given by Kendon M. et al. (2023). They note that 2022 was the warmest not only in terms of air temperature, but also of water near the coast in almost 150 years of research.

Tomczyk A.M. et al. (2021) outline the impact of climate change on the decrease in snowfall in Poland over the past 54 years.

In the article, Paul M.J. et al. (2019) provide multi-year observational data on the impact of air temperature change on precipitation, water temperature, and water quality in the United States.

The main reason for this is the greenhouse effect, which is caused by greenhouse gases such as water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), etc. Increasing greenhouse gas emissions provoke extreme climate changes, such as floods, droughts, and heat, which induce reactive oxygen species and oxidative stress in plants (Cassia R. et al., 2018).

In order to meet the global demand for food, humanity is forced to increase the number of animals, but this does not necessarily lead to a proportional increase in GHG production.

Livestock farming, especially large ruminants, and its related products make a significant contribution to anthropogenic emissions of the highly active GHGs methane and nitrous oxide (MacLeod M.J. et al., 2018). According to Gerber P.J. et al. (2013), global livestock production contributes to approximately 7.1 Gigatons of CO_2-equivalent emissions. The amount of GHG from domestic animals is equal to 14.5% of anthropogenic emissions of greenhouse gases every year, of which CH_4 from livestock is about 44% of this total amount. The production of beef and milk from cattle accounts for the majority of emissions – 41% and 20% of the sector's emissions, respectively. These indicators from the pig and poultry industries (meat and eggs) are 9% and 8%, respectively. Feed production and processing account for 45% of emissions, ruminant intestinal fermentation for 39%, manure storage and processing for 10%, and the rest for processing and transporting animal products.

Achieving net "zero emissions" of long-lived climate pollutants (LLCPs), primarily carbon dioxide (CO_2) and nitrous oxide (N_2O), is considered vital to halting the warming trend.

The food system is the main cause of increased CO_2 emissions due to land-use change, mainly as a result of clearing land for crops or pasture. Net CO_2 emissions associated with land use are estimated to be about 14% of annual anthropogenic CO_2 emissions (Le Quéré S. et al., 2018).

Shorter-lived greenhouse gases than carbon dioxide are automatically removed from the atmosphere over a shorter period of time, so emissions will not continue to accumulate for a very long time like CO_2. These are methane and nitrous oxide.

Methane in livestock farming is mainly produced as a result of intestinal fermentation and manure handling. Methane as a result of enteral fermentation is a by-product of the digestion of feed materials, mainly roughage. Most CH_4 from ruminants is produced in the rumen and is exhaled or regurgitated by the animal. During enteral fermentation in the rumen, methanogenic microorganisms generate CH4 from hydrogen (H_2) and CO_2 produced by protozoa, bacteria, and anaerobic fungi (Martin S. et al., 2010; Morgavi D. et al., 2010; Tapio I. et al.., 2017).

As reported by Shibata M. and Terada F. (2010), the amount of CH_4 emissions depends on animals (i.e. type of digestive tract, stage of production, age and weight), feed (i.e. quality, quantity and composition) and environmental temperature. The amount and quality of forage affects the amount of energy, nitrogen and minerals available to microorganisms in the rumen. The protein content of the feed has a negative effect on CH_4 production, while the fiber content has a positive effect.

According to the US Environmental Protection Agency (EPA, 1995), only a small part of CH_4 is produced in the large intestine of ruminants and is excreted through flatulence.

According to Aguirre-Villegas H.A. and Larson R.A. (2017), manure (faeces and urine) is the second largest source of GHG emissions after enteric methane, accounting for about 7% of agricultural CH_4 and N_2O emissions.

Ruminants do not convert nitrogen well – only 5–30% of consumed is assimilated, and the remaining 70–95% is excreted in faeces and urine (Luo J. et al., 2010).

According to Dangal S.R.S. et al. (2019), about 2.2 million tons of N_2O–N are emitted annually from pastures in the world, including 74% from anthropogenic sources. Animal feces and urine are the largest source of N_2O emissions in pastures (54%), followed by manure (13%) and nitrogen fertilizers (7%).

In order to reduce GHG emissions throughout the world, and in Ukraine in particular, numerous studies are being conducted in this direction. Thus, Pinchuk V.O. and Borodai V.P. (2019) calculated the emission of ammonia (NH_3), nitrous oxide (N_2O) and methane (CH_4) from by-products of animal origin (manure) in different regions of Ukraine, categories of farms, types of farm livestock and systems of cleaning, storage and use of manure in Ukraine according to the IPCC methodology.

Emission reduction methods (low-emission housing systems) for various types of domestic animals have been developed and proposed (Furdychko O.I. et al., 2016).

Some scientists suggest making adjustments to the composition of diets (van Cleef F.O.S. et al., 2022; Bica R. et al., 2022), or using feed additives to reduce greenhouse gas emissions (Owens J.L. et al., 2020).

Others propose to process animal manure. For example, adding the natural mineral glauconite to the dung substrate of cows can reduce the level of CO_2 and CH_4 by 5%, respectively (Vorobel M. et al., 2018). And the use of superphosphate and slaked lime in different ratios to pig manure contributes to the reduction of carbon dioxide emissions by 6.1-25.5%, methane by 3.8-11.5%, and nitrogen oxide by 5.4-17.4%, respectively % (Vorobel M., 2022).

In 1988, the Intergovernmental Panel on Climate Change (IPCC) was established. The purpose of its creation is the coordination of scientific activities to determine the amount of GHG emissions, the development of calculation methods, their refinement and adaptation to national conditions, and the assessment of scientific knowledge related to climate change. The Intergovernmental Panel's mission is to provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risks, as well as options for adaptation and mitigation.

In the methodology of the IPCC (2006), it is noted that effective practice should meet the need to use assessment methods for each country, in particular gross energy consumption, based on the use of methods specifically defined for that country. To determine the gross energy in the proposed methodology of effective practice, the values of the indicators of net energy for maintaining the vital activity of the animal, physical activity, lactation, work, physicality, and digestive energy are used.

For more efficient processing of livestock by-products (organic waste) on farms, it is recommended to separate them into solid and liquid fractions. This makes it

possible to reduce direct emissions of GHG to the atmosphere, improve processing and disinfection of manure, as well as its processing in biogas plants. However, this practice is not widespread in Ukraine. Thus, according to the data of the Association of Pig Breeders of Ukraine, among farms with a herd of 1,000 to 50,000 pigs, when manure is prepared for use, separation into solid and liquid fractions occurs only in 43%.

In the methodology of effective practice, there are no approaches for determining greenhouse gas emissions during the preparation of livestock by-products using fractionation technologies, as well as approaches for determining the output of organic waste (IPCC, 2006).

The purpose of the work is to expand the approaches to obtaining raw data for determining greenhouse gas emissions from livestock by-products within the framework of the effective practice of the methodology of the Intergovernmental Group of Experts on Climate Change.

Research materials and methods. When expanding the approaches for obtaining initial data for determining greenhouse gas emissions from by-products of livestock farming to determine gross energy, indicators of the content of crude protein (CP), crude fat (CF), crude fiber (CFb), and non-nitrogen extractive matters (NES) in the diet were used according to DSTU 8066:2015[1].

When separating livestock by-products (organic waste) into solid and liquid, the actual data characterizing the quality of separation on individual elements of the technological line (units, devices and installations) are the mass and moisture content of effluents entering processing and obtained at the exit, mass and the moisture content of the liquid fraction and the mass and moisture content of the solid fraction (Piskun V., 2007).

On the basis of the balance equations of the mass consumption of the jet through the separation element, the following data can be obtained: efficiency of separation into liquid and solid fractions; concentration of dry matter in liquid and solid fractions of effluents.

Research results. Based on the characteristics of animal rations, gross energy is determined taking into account the structure of the herd and feed according to the formula (DSTU 8066:2015[1]):

$$GE = 0.240*CP + 0.398*CF + 0.201*CFb + 0.175*NES \qquad (1)$$

where GE is gross energy, in MJ/kg of dry matter;
CP is crude protein content in the dry matter of the forage, %;
CF is crude fat content in dry matter, %;
CFb is crude fiber content in the dry matter of the forage, %;
NES is the content of nitrogen-free extractive matters in dry matter, %;

As an example, Tables 1 and 2 show the results of the evaluation of the zoochemical composition of feed and calculations of gross energy consumption by cows of the "Hontarivka" branch of the "Hontarivka" State Enterprise of the Kharkiv region. The zoochemical composition of feed was evaluated at the testing center of the Institute of Animal Husbandry of the National Academy of Agrarian Sciences of Ukraine. According to the calculations, it was established that the gross energy of the ration of a dairy cow is 363.5 MJ, and that of a dry cow is 191.1 MJ.

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[1] DSTU 8066:2015. (2015). Feed fr farm animals. Methods for determining of energy content and nutrient value. *Derzhspozhivstandard.* Kyiv. 15 p.

Table 1

**Assessment of the composition of fodder at SE SF "Hontarivka",
the Kharkiv oblast**

The name of the type of test, measurement unit	Test results					
	Silage		Hay		Combined feed	
	on natural wet matter	on completely dry matter	on natural wet matter	on completely dry matter	on natural wet matter	on completely dry matter
Wet matter, %	73.71	0	10.35	0	10.41	0
Dry matter, %	26.29	100	89.65	100	89.59	100
Ash, %	1.60	6.09	5.91	6.59	5.01	5.59
Crude fat, %	2.46	9.36	1.03	1.15	2.64	2.95
Total nitrogen, %	0.352	1.339	0.953	1.063	2.317	2.586
Crude protein, % (N × 6.25)	2.20	8.37	5.96	6.65	14.48	16.16
Crude fiber, %	7.82	29.75	36.90	41.16	4.78	5.34
NES, %	12.21	46.44	39.85	44.45	62.68	69.96
Calcium, %	0.209	0.795	0.981	1.094	0.483	0.539
Phosphorus, %	0.049	0.186	0.228	0.254	0.428	0.478
Exchange energy, MJ	2.60	9.89	6.70	7.48	10.94	12.21

Further, within the framework of the effective practice of the IPCC methodology, we determine the rates of release of volatile solids taking into account the obtained values of gross energy by sex and age groups and the coefficient of methane emissions.

Table 2

Consumption of gross energy by cows at SE SF "Hontarivka", the Kharkiv oblast

Fodder	Quantity of fodder, kg	Content, %					Gross energy per head, MJ	Gross energy for all livestock, MJ
		Dry matter	Protein	Fat	Fiber	NES		
Dairy cows n=284								
Combined feed	8	89.59	16.16	2.95	5.34	69.96	131.7	37389.5
Silage	32	26.29	8.37	9.36	29.75	46.44	166.9	47404.4
Hay	4	89.65	6.65	1.16	41.16	44.45	64.9	18443.2
Total							363.5	103237.1
Dry cows n=86								
Combined feed	2	89.59	16.16	2.95	5.34	69.96	32.9	2830.26
Silage	21	26.29	8.37	9.36	29.75	46.44	109.5	9420.44
Hay	3	89.65	6.65	1.16	41.16	44.45	48.7	4187.34
Total							191.1	16438.04

Fattening cows n=13								
Combined feed	6	89.59	16.16	2.95	5.34	69.96	98.7	1283.62
Silage	32	26.29	8.37	9.36	29.75	46.44	166.9	2305.55
Hay	3	89.65	6.65	1.16	41.16	44.45	48.7	632.97
Total							324.8	4222.14
Non-calved cows n=65								
Combined feed	2	89.59	16.16	2.95	5.34	69.96	32.9	2139.15
Silage	21	26.29	8.37	9.36	29.75	46.44	109.5	7120.1
Hay	3	89.65	6.65	1.16	41.16	44.45	48.7	3164.85
Total							191.1	12424.1

The value of the rate of release of volatile solids will be determined by equation (2):

$$VS = \left[GE \cdot \left(1 - \frac{DE\%}{100} \right) + (UE \cdot GE) \right] \cdot \left[\left(\frac{1 - ASN}{18.45} \right) \right];$$ (2)

where *VS* is the release of volatile solids per day based on the mass of dry organic matter, kg *VS*/day;

GE is gross consumed energy, MJ/day;

DE is feed digestibility, in percent (for example, 60%);

(*UE GE*) is energy lost in urine (urine energy), expressed as a fraction of GE. For most ruminants, the energy lost in urine can generally be assumed to be 0.04 *GE* (reducing to 0.02 for ruminants and in pig diets containing 85% or more grain).

ASN is the ash content of the manure, calculated as a fraction of the dry matter intake of the feed (for example, 0.08 for cattle).

18.45 is the conversion factor for *GE* ration based on 1 kg of dry matter (MJ/kg).

To determine the emission of greenhouse gases in the form of direct and side emissions of N_2O, it is necessary to know the daily output of livestock by-products. However, in the effective practice of the IPCC methodology, there are no approaches to determining the daily yield of livestock by-products. The daily yield of animal by-products can be calculated by formula (3) (Piskun, V., 2007):

$$Q_m = Q_{ex} + L + I + D + W_p + W_r,$$ (3)

where Q_{ex} is the mass of excrement, kg per day;

L is litter mass, kg per day;

I is mass of extraneous inclusions, kg per day;

D is mass of feed residues, kg per day;

W_p is mass of process water, kg per day;

W_r is is the mass water used to remove manure from the premises, kg per day.

The output of animal excrement is calculated based on the weight and composition of feed:

$$Q_{ex} = k_u * \left(1 - \frac{k_d}{100}\right) * R_t * \frac{O_r}{O_e} \qquad (4)$$

where k_u is is the coefficient of use of fodder;

k_d is weighted average coefficient of digestion of organic matter of the diet by animals, %;

R_t is total weight of feed ration, kg;

O_r is relative content of organic matter in the feed ration, %;

O_e is the relative content of organic matter in excrement, %.

The average weighted coefficient of digestion of organic matter is calculated according to formula (5):

$$k_d = \frac{\sum_{j=1}^{m} R_j * O_{rj} * k_{nj}}{\sum_{j=1}^{m} R_j * O_{rj}} \qquad (5)$$

where m is the number of feed types included in the ration;

R_j is the mass of the type of fodder included in the ration, kg;

k_{nj} is coefficient of digestion of organic matter of the jth feed;

O_{rj} is the relative content of organic matter in the jth feed, %.

The relative content of organic matter in the ration is determined by formula (6):

$$O_r = \frac{\sum_{j=1}^{m} R_j * O_{rj}}{\sum_{j=1}^{m} R_j}, \qquad (6)$$

According to the presented formulas, the yield of manure was determined due to the amount of organic matter in the ration for a group of 7 cows. It was established that the output was 5.194±0.177 kg of organic matter on average for the group. And the actual output of manure, according to the data of the balance experiment, conducted in the conditions of the physiological yard of IAH of the National Academy of Sciences, amounted to 5.018±0.437 kg.

Separation of livestock by-products into fractions. Liquid waste is a big problem for any livestock enterprise. In places of their accumulation, a number of problems arise, related to environmental pollution, ecological deterioration, the possibility of poisons entering water bodies (including those included in the water intake system).

In the presence of own fields, the problem seems to be less, but the effluents can be applied as fertilizers, no earlier than after 12 months, after the effluents have undergone a natural composting process. Thus, even long-term composting retains the potential danger of infection. In the absence of fields, the problem of disposing of sewage becomes unsolvable.

The removal of solid particles from sewage, that is, the separation of livestock by-products into fractions, is a key point in solving this problem, the purpose of which is to reduce the content of polluting components of manure, which will allow to reduce the volume of settling tanks, simplify the application technology, increase the efficiency of biological treatment and minimize the harmful impact on the environment, reduce unpleasant scent a minimum.

Storing livestock by-products in open storage facilities does not contribute to a significant reduction in the amount of GHG emissions into the atmosphere, so in developed countries, closed storage facilities have begun to be built. Therefore, the question arises – why not use them as tanks for settling and separating fractions into liquid and solid with subsequent use in a biogas plant to obtain biofuel.

Livestock by-products are often used as a substrate for anaerobic digestion, as they have a neutral pH and the mix of microbes needed for this process naturally. In addition, animal by-products are often used as a basis for anaerobic digestion because many wastes are acidic, contain little natural microbes and nutrients necessary for anaerobic digestion, such as trace elements, vitamins, nitrogen, etc. (Mahmudul H.M. et al., 2021). Also, to ensure optimal technological parameters of methane fermentation, effluents are prepared with their separation into sediment and liquid fraction. Reducing the amount of lignocellulosic material due to fractionation will allow to accelerate the process of anaerobic fermentation and, accordingly, the processing of GHG into biofuel (Li Y. et al., 2020).

The actual data characterizing the quality of waste separation on individual elements of the technological line (units, devices and installations) are the mass M and moisture W of the wastes entering the treatment and received at the exit, the mass M_l and moisture W_l of the liquid fraction and the mass M_s and moisture W_s solid fraction (Piskun, V., 2007).

The following data are obtained on the basis of the balance equations of the mass consumption of the jet through the separation element:

h_l, h_s – efficiency of separation into liquid and solid fractions;

C_l, C_s – concentration of dry matter in liquid and solid fractions of effluents.

Three main options for obtaining separation parameters are considered:

1. If M, W, W_l, W_s are given, then the last characteristics of the separation quality are determined by formulas (7):

$$M_s = M * (W_l - W) / (W_l - W_s); \tag{7}$$

Giving an example, wastewater output during pork production is 250 tons of manure with a moisture content of 95.4%. When divided into fractions, a liquid fraction with a moisture content of 98.5% and a solid fraction with a moisture content of 75.3% are obtained. According to formula 6, 38.87 tons of solid fraction and 211.13 tons of liquid fraction will be obtained. To determine greenhouse gas emissions from solid and liquid fractions, we determine the gross energy in the fractions based on the indicators of the content of CP, CF, CFb, NES according to DSTU 8066: 2015.

The elements are determined according to the equations below.

$$M_l = M * (W - W_s) / (W_l - W_s) \text{ або } M_l = M - M_s;$$
$$C_l = 1 - 0{,}01 * W_l; \quad C_s = 1 - 0{,}01 * W_s; \quad C = 1 - 0{,}01 * W;$$
$$h_l = 1 - (M_l * C_l) / (M * C) = 1 - [M_l \cdot (100 - W_l)] / [M \cdot (100 - W)];$$
$$h_s = 1 - (M_s * C_T) / (M * C) = 1 - [M_s * (100 - W_s)] / [M * (100 - W)] \text{ or}$$
$$h_s = 1 - h_l \tag{8}$$

2. If M, W, h_p, W_s are specified, then M_l, M_s, W_l, h_s are determined by formulas (9):

$$M_s = M * h_l \cdot (100 - W) / (100 - W_s); \qquad M_l = M - M_s;$$
$$h_s = 1 - h_l; \qquad W_l = 100 - M * h_s / (100 - W) * M_l. \tag{9}$$

3. If M, W, h_l, W_l are given, then M_l, M_s, W_s, h_s are determined by formulas (10):

$$h_s = 1 - h_l; \quad M_l = M * h_s \cdot (100 - W)/(100 - W_l); \quad M_s = M - M_l;$$
$$W_s = 100 - M * h_l \cdot (100 - W)/M_s. \tag{10}$$

The proposed approaches to the methodology for estimating greenhouse gas emissions from livestock by-products from the determination of gross energy through the value of crude protein, crude fat, crude fiber and nitrogen-free extractive matters in the dry matter of feed and the quality of separation on individual elements of the technological line in the technologies of preparation for use will allow to increase the accuracy determination of greenhouse gas emissions.

Discussions. Efficient practice in the IPCC methodology uses the determination of gross energy (GE) for cattle and sheep based on the total net energy required and the energy availability characteristics of the forage(s) (Equation 11)

$$GE = \left[\frac{\left(\dfrac{NE_m + NE_a + NE_l + NE_{work} + NE_p}{REM} \right) + \left(\dfrac{NE_g + NE_{wool}}{REG} \right)}{\dfrac{DE\%}{100}} \right] \tag{11}$$

where: GE = gross energy, MJ/day;

NE_m = net energy needed to support the animal, MJ/day;

NE_a = net energy for physical activity of the animal, MJ/day;

NE_l = net energy for lactation, MJ/day;

NE_{work} = net energy for work, MJ/day;

NE_p = net energy required for pregnancy, MJ/day;

REM = ratio of net dietary energy available for maintenance to digestible energy intake;

NE_g = net energy required for growth, MJ/day;

NE_{wool} = net energy required for wool production during the year, MJ/day;

REG = ratio of net energy in the diet available for growth to digestible energy consumed;

$DE\%$ = digestible energy expressed as a percentage of gross energy.

It should be outlined that the values of net energy required to maintain the vital activity of the animal, net energy for physical activity of the animal, net energy for lactation, net energy for work, net energy required for pregnancy are determined by other formulas. To use these formulas, you need to know net energy for animal growth, average body weight per herd, body weight of an adult female, body weight of an adult female of average fatness, average daily weight gain of an animal per herd, amount of milk produced per day, fat content in milk, number of working hours per day, etc. It is also necessary to know the ratio of net energy in the ration, which is available for life support, to the easily digestible energy consumed, as well as the ratio of the net energy in the ration, which is available for growth, to the easily digestible energy consumed, easily digestible energy, which is expressed as a percentage of gross energy. This is in case we define gross energy.

The analysis of literary sources showed that in practice determination of methane emissions due to gross energy, which is determined according to the above formula 9, is practically not carried out. For this, the simplest method of determining GHG

emissions is used by the emission coefficient for the corresponding livestock according to formula 11 (Pinchuk, V.O., Borodai, V.P., 2019; Das N.G. et al., 2020):

$$CH_{4manure} = \sum_{(A)} \frac{EF_{(A)} * N_{(A)}}{10^6}, \qquad (12)$$

where $CH_{4manure}$ is CH_4 emissions as a result of cleaning, storage and use of manure for the established animal population, thousand t/year;

$EF_{(A)}$ is the emission coefficient for the established animal population, CH_4 kg/head/year (IPCC, 2006);

$N_{(A)}$ is average annual population of the A species/categories of animals; A – species/category of animals.

The emission coefficient for the established animal population depends only on the average annual temperature and climatic conditions and does not include data on the influence of the amount of gross energy in the animal ration on its (coefficient) value.

According to the State Statistics Service of Ukraine, milk yield per cow in 2006 was 3,896 kg, and in 2022 – 5,119 kg. Nevertheless, the same coefficient is used to determine methane, without taking into account livestock productivity.

Therefore, the determination of methane emissions through the indicator of gross energy of feed, taking into account crude protein, crude fat, crude fiber and non-nitrogenous extractive matters, is simpler and more accurate.

References include a CH_4 prediction equation formulated by Shibata, M. & Terada, F. (2010) using only dry matter intake (DMI) and adopted in Japan to estimate emissions from ruminants for the National Greenhouse Gas Inventory Report :
$$Y = -17{,}766 + 42{,}793X - 0{,}849X^2,$$

where Y is CH_4 production (l/day),
X is DMI (kg/day).

It should be noted that using the equation for forecasting CH_4 emissions only using the dry matter consumption indicator leads to some inaccuracy. After all, in different rations with the same amount of dry matter, but different amounts of crude protein, crude fat, crude fiber and non-nitrogen extractive matters, when calculating emissions, a distinctive result with a significant error will be obtained.

Therefore, the authors believe that the proposed calculation approach is more accurate and easier to use in practice.

Conclusions. As part of the effective practice of the methodology of the Intergovernmental Panel on Climate Change (IPCC), the authors propose to expand the approaches to obtaining raw data for determining greenhouse gas emissions from livestock by-products:

- to determine gross energy, use the value of crude protein, crude fat, crude fiber and nitrogen-free extractives;

- the output of animal excrement should be calculated based on the weight and composition of feed, taking into account the digestibility coefficient of organic matter of the *j*th feed and the relative content of organic matter in the *j*th feed;

- on the basis of the balance equations of the mass consumption of the jet through the separation element, obtain the following data: efficiency of separation into liquid and solid fractions; concentration of dry matter in liquid and solid fractions of effluents.

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