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Investigation of the energy efficiency of biotechnical systems in electrotechnological complexes

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Abstract

The main task of agro-industrial production is to provide the population with food products for the production of which energy is expended in the form of electricity, technical means, fuels and lubricants, mineral fertilizers, etc. Accordingly, we have developed a concept and general methodological principles for the analysis of ecological and biotechnical systems in animal husbandry, it makes it possible to simulate the influence of various factors on the energy and ecological efficiency of systems, to compare and search for energy-saving modes and technologies. General methodological principles have been developed for the analysis of energy efficiency and environmental safety of agricultural ecological and biotechnical systems, which are based on the definition of the bioenergy efficiency coefficient, the quantitative expression of which is the ratio of energy accumulated in products to the total energy consumption for its production. This makes it possible to model with sufficient accuracy the influence of various factors on the energy and environmental efficiency of the system, to compare and search for energy-saving modes and technologies in order to find and select the most energy efficient ones to increase the energy efficiency of the complex.

Keywords: Energy Saving, Electrified Technologies, Ecology, Mathematical Model, System, Electrotechnological Complex.

Major classifications: Bioenergy.

1. Introduction

The solution to the food problem in Ukraine is impossible without a further increase in the production of livestock products, and consequently, the construction of new ones, reconstruction and improvement of the efficiency of operation of existing livestock complexes with industrial technology and a high level of electrification and automation of production processes. The normal functioning of such production facilities depends on two factors: reliable supply of energy and material resources and environmental protection from the harmful effects of waste from these complexes. Since these factors on livestock complexes are interrelated and interdependent, it is advisable to consider them in the ecological and biotechnical system "livestock production - processing and waste disposal - environment". The complexity of assessing the efficiency of the functioning of electrotechnological complexes lies in the fact that energy technologies affect living objects: plants and animals, therefore the choice of possible energy flow

s differs significantly from other industries (Boltyanska et al., 2020).
The production of any product is not just the cost of production, receipt of products, and waste output, but also energy losses that can be due to: a low level of automation; irrational ventilation system; ineffective lighting syste m, lack of modernization of premises, outdated and ineffective technologies of suppuration and disposal (Zielinska-Sitkiewicz et al., 2018).
The purpose of the research is - to develop general methodological principles for assessing energy-saving and env ironmentally friendly technologies of livestock enterprises based on mathematical models of energy flows in the fo rm of separate criteria for solving the problems of designing and operating agricultural ecological-biotechnical syst ems.

2. Basic Research Materials

For a comprehensive and in-depth analysis and forecasting of production and economic processes in pig-feeding complexes, calculation methods in the form of an energy balance are widely used.
An important priority in the agricultural sector of Ukraine is the development of the animal husbandry industry, although today animal husbandry cannot be considered the optimal form of business. At the same time, large agricultural holdings are developing in which a full cycle of production passes through a limited area, hundreds and thousands of animals, or millions of birds, are placed simultaneously. Such large enterprises consume a large amount of resources, and, accordingly, much more and more extensive waste accumulation are generated than local utilization (Honcharuk, 2020).
As a result of studies of the basic requirements for system analysis, such a plan has been developed to implement a systematic approach to assessing the energy efficiency and environmental safety of agricultural ecological-biotechnical systems: problem statement - defining the boundaries of the system under study; systematization and processing of initial information for solving the problem; compilation of a mathematical model of an agricultural ecological-biotechnical system and its subsystems, taking into account direct, reverse, vertical and horizontal links between them and the environment; determination of parametric connections, restrictions and permissible zones of change of parameters for a given structural diagram of an agricultural ecological-biotechnical system; the formulation of target (criterion) functionals for assessing the compliance of the system with the assigned tasks.

3. Results of the research

We represent the agricultural ecological and biotechnical system in the form of four interconnected subsystems: subsystems of livestock production (B), where biological and technological factors have a decisive influence on the amount of consumed natural resources and the waste generated by this; subsystem of waste processing and utilization (P), which ensures the processing and disposal of waste before disposal into the environment and the use of waste as raw material for the production of useful products (protein feed, valuable organic fertilizers, biogas) of the ecological subsystem (E), which covers natural objects and environmental management processes (air, water bodies, soil) of the managing subsystem (M) - the managing of human actions, software, programs and control algorithms.

The basis for maintaining the ecological balance of the agricultural ecological-biotechnical system as a whole is the direct mutual utilization of waste, as well as the production of energy (biogas) and raw materials (fodder protein, fertilizers) resources from waste.

The development of a general mathematical model of an agricultural ecological-biotechnical system will be carried out on the basis of flows of energy and matter.

Let the real ecological-biotechnical system in the electrotechnological complex be given:

a) the structure of interconnected elements of the biological, technological and control parts of the agricultural ecological-biotechnical;

b) the composition of streams, including: a set of input streams - X_B, X_P, X_E; many output streams: Y_1 - livestock products (meat, milk, eggs, etc.), Y_P - waste disposal products; Y_{Ep} - ecosystem products (food, water); Z_R, Z_D, Z_E - removal and dispersion of energy and substances; PB_O, PO_O, PE_B, P_{OE}, P_{OB}, - livestock waste generation, waste treatment and disposal and ecosystems; c) properties, relations and the interaction algorithm of subsystems B, P, E, M;

d) the purpose of the agricultural ecological-biotechnical system and its subsystems, which is to produce the maximum amount of livestock products with the minimum consumption of energy and substances and the environmental safety of technological processes.

We represent the state of the agricultural ecological-biotechnical system by the vector S, the components of which are functions of time t and space R.

A change in state occurs as a result of random actions ξ (t, R) and management strategies u:

$$U = (g, \lambda) \tag{1}$$

where $g \in N^k$ - diagrams of technological processes included in the N^k space (feeding technology, keeping animals, waste treatment and disposal schemes, etc.); $\lambda \in H^m$ - a set of elements of technological processes included in the space H^m (machines, mechanisms, etc.).

Formally, we represent the system as

$$S(t) = A(S(\tau), \quad U \tag{2}$$

where A (·) is an operator that determines the state of the agricultural ecological-biotechnical system at the time moment t $\in [t_0, T]$ by the value of the vector S (t), $\tau \in [t, t_0]$.

It is known that modern livestock enterprises are ineffective, energy producers and ecologists are unsafe.

It is necessary on the set M to determine the discrepancy in the rates of turnover of energy and substances in the production and natural subsystems, which leads to the emergence of inconsistent ecological-biotechnical relations, to find such a management strategy $U_0 \in M$, which, with the restrictions on resources $X_i \in X$ and the capacity of the surrounding natural environment H_c, provided a maximum functional

$$F_i = \varphi\{\eta_i^{be}(U_i), \eta_i^{es}\} \underset{max}{\longrightarrow} \tag{3}$$

where η_i^{be} (u_i) is an indicator of bioenergy efficiency of management strategies; η_i^{es} (u_i) is an indicator of environmental safety; φ - operator of convolution of criteria.

It is possible to write three systems of equality and irregularities in scalar form, so that three systems and interferences in subsystems *B, P, E.*

Subsystem B "livestock production":

$$\sum_{\lambda \in H^m} X_{i\lambda}^B(t) - \sum_{j=1} \sum_{\lambda \in H^m} a_{ij\lambda} X_i^B(t) - \sum_{j=1} Z_i^B(t) = Y_i^B(t) \geq Y_0^B(t);$$

$$\sum_{j \in I^B} \sum_{\lambda \in H^m} P_{i\lambda}^{rc} X_i^B(t) = P_i^{PB}(t) + P_i^{EB}(t);$$

$$\sum_{j \in I^B} \sum_{\lambda \in H^m} -P_{i\lambda}^f X_i^B(t) = P_\gamma^{BP}(t) + P_\gamma^{BE}(t); \tag{4}$$

$$\sum_{j \in I^e} \beta_{i\lambda}^{pc} X_i^B(t) - \sum_{\tau=1}^{t} N_\lambda^B(t) \leq N_{\lambda 0},$$

where $Y^b{}_r$ - restrictions on the output of livestock products; $\alpha_{ij\lambda}$ is the coefficient of expenditures of the j - type of resources for the production of the *i* - type of product at the λ - m unit; $P_{i\lambda}^{rc}$ - specific coefficient of resource consumption; $P_{i\lambda}^f$- specific coefficient of γ - those types of waste generated in the production of the i-th type of product at the λ-th unit;

$\beta_{i\lambda}^{pc}$ is the coefficient of the production capacity of the λ-th unit in the production of the *i*-th type of livestock products; N_{λ}^{B}- increase in the production capacity of the λ-th unit; $N_{\lambda 0}$ is the production capacity of the λ-th unit.

Subsystem P "Waste treatment and disposal":

$$\sum_{g \in H^k} X_{\gamma g}^{P}(t) - \sum_{\gamma \in H^n} \sum_{\lambda \in H^k} a_{\gamma l g} X_i^P(t) - \sum_{l} Z_i^P(t) = Y_i^P(t) \geq Y_0^P(t);$$
$$\sum_{\gamma \in I^n} \sum_{g \in H^k} P_{ig}^{rc} X_i^P(t) = P_m^{BP}(t) + P_m^{BE}(t); \qquad (5)$$
$$\sum_{\gamma \in I^n} \sum_{g \in H^k} P_{ig}^{f} X_{\gamma g}^P(t) = P_m^{PE}(t) + P_m^{BE}(t) \leq H_e;$$

$$\sum_{\gamma \in I^n} \sum_{g \in H^k} \beta_{1\lambda g} X_{\gamma g}^P(t) = \sum_{\tau=1}^{t} N_{\gamma g}^P(\tau) \leq N_{\lambda g}^P;$$

where Y_0^P- restrictions on the release of l-th products; aγlg is the coefficient of expenditures of the γ -th type of waste in the production of the l -th type of product at the g-th technological module; P_{ig}^{rc}- specific coefficient resource consumption in the production of the l -th type of product at the g-th technological module; P_{ig}^{f} - the specific coefficient of generated m-their types of waste; H_e - storage of the surrounding natural environment; $\beta_{1\lambda g}$ is the coefficient of the production capacity of the λ-th unit in the production of the i-th type of livestock products; $N_{\lambda g}^P$ is the increase in the production capacity of the λ-th unit at the g-th technological module.

Subsystem E "Ecosystem":

$$\sum X_i^E(t) - \sum_{r \in H^p} \sum_{\lambda \in H^m} \alpha_{rg\lambda} X_i^E(t) - \sum_{q} Z_i^E(t) \geq Y_0^P(t);$$
$$Y_0^E(t) = Y_0^{E-1} + \sum_{r \in I^p} \sum_{\lambda \in H^m} \alpha_{rg\lambda} X_i^E(t) \leq L_{\gamma}^E; \qquad (6)$$
$$\sum_{g \in H^p} \beta_{q\lambda} X_i^E(t) - \sum_{\tau=1}^{t} N_{\lambda q}^E(\tau) \leq N_{\lambda q},$$

where $\alpha_{rg\lambda}$ is the coefficient of expenditures of the r-type of resources in the production of q-th products on the λ-th unit; L_{γ}^E is the maximum dose of the toxicant.

To assess the effectiveness of new technology, as well as to optimize the operating modes of equipment, the most widespread methodology is based on the criterion of reduced costs (Yakubov, 2013). But in the minds of inflation and economic crisis, when prices grow quickly, it has become practically untenable to give an additional economic assessment. Under these conditions, the efficiency of energy resources use in animal husbandry and the search for energy-saving technologies should be carried out with the help of systemic bioenergy analysis, which is based on the determination of the bioenergy efficiency coefficient and the quantitative expression of which is the ratio of the energy accumulated in the product (energy content of the product) to the total energy consumption for its production (energy intensity of products):

$$\eta_{be} = \frac{E_{lp}}{\sum_{i=1} \sum_{j=1} c_{ij}^k X_{ij}^k} \qquad (7)$$

where E_{lp} is the energy content of livestock products, GJ/lb; C_{ij}^{k} - energy equivalent of the k-th element of the i-th type of expenses for each technological process j, GJ / (lb, m^2, man hour); X_{ij}^{k} is the value of the k-th element of the i-th type of expenses for each technological process j, (lb, m^2, man hour); i, k - types of costs and their elements: direct (electricity, fuel and lubricants), indirect (for the production of feed, breeding animals, medicines, etc.), investment (machines, structures, etc.), living labor (workers, office workers); j - technological processes (feeding, milking, manure removal, maintaining a microclimate, etc.).

This approach allows one to take into account not only the direct costs of energy and fuel, but also the materialized earlier in various sectors of the national economy, as well as the costs of living labor of workers and employees.

The total costs of all types of resources are listed in the corresponding energy units, combining costs into a single system of energy indicators. At the same time, energy equivalents for means of production include energy spent on the extraction of raw materials, their processing, manufacture and transportation of machinery and equipment, as well as energy for the manufacture of spare parts and repairs. When developing energy equivalents, it was taken into account that only part of the total energy is transferred to products annually by machinery and equipment (Chmil, 2015) .

The definition of the total annual energy consumption (Denisyuk et al., 2016) is shown as the sum of all components of energy consumption:

$$E_d = E_{sl} + E_f + E_{fa} + E_{wc} + E_{lw} \quad (8)$$

where E_{sl} is the total energy materialized in the staged livestock, GJ;
E_f is the total energy materialized in the feed. GJ;
E_{fa} - total energy transferred by fixed assets (except livestock), GJ;
E_{wc} - total energy transferred by working capital (except feed), GJ;
E_{lw} - energy of living work, Gj.

As a basis for calculating energy flows in animal husbandry, we took a promising model of a pig farm for 3 thousand heads, the results are shown in Table 1.

An important issue for effective pig rearing is the optimal capacity of the pig feeding complex. Figure 1 shows the values of the coefficient of bioenergy efficiency on models of complexes with a capacity of 3 thousand - 54 thousand. The most optimal according to the graph (Fig. 1) is a complex with a capacity of 54 thousand heads.

Table 1: Energy consumption at the pork production complex for 3 thousand heads

Types of expenses	Energy costs Gj			Percentage of the amount (%)
	In just one year	On one head	1 quintal of growth per year	
Premises and structures	16933	5,644	5,08	31,81
Electricity: Microclimate Lighting	 285 180	 0,095 0,06	 0,086 0,054	 0,54 0,34
Live work	231	0,077	0,07	0,44
Feed	219	0,073	0,066	0,41
Energy consumption for water	180	0,06	0,054	0,34
Veterinary drugs	714	0,238	0,215	1,35
Staging livestock	31686	10,562	9,506	59,52
Equipment	2799	0,933	0,84	5,26
As a whole	53227	17,742	15,971	

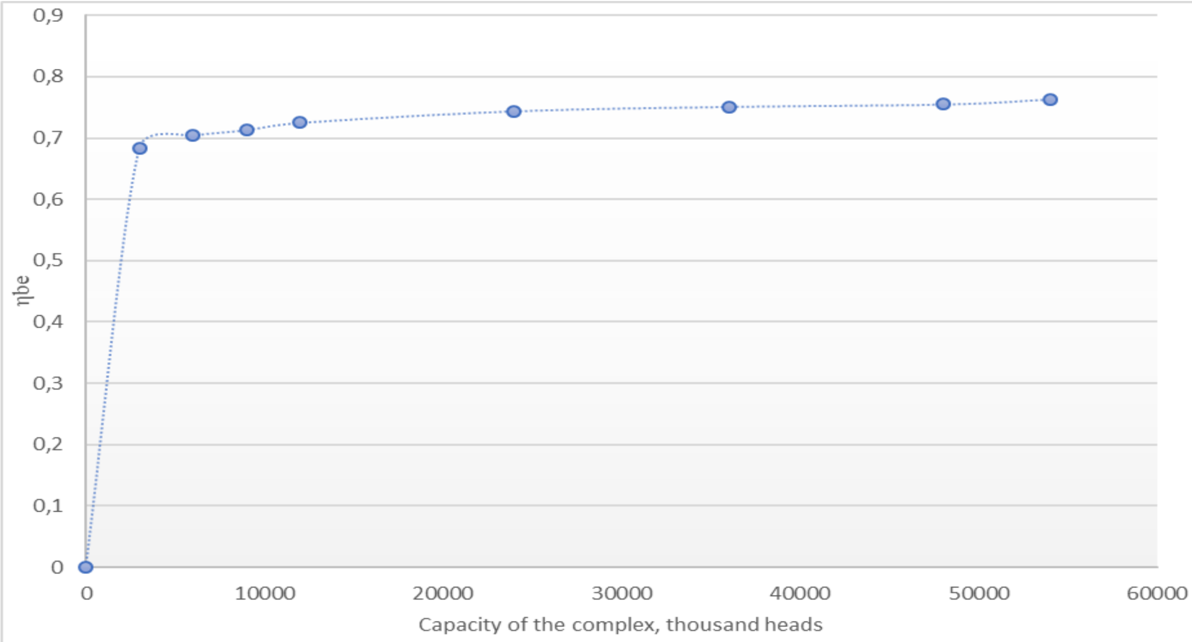

Figure 1: Dependence of the coefficient of bioenergy efficiency on the capacity of the complex

The indicators defined above are interrelated and each of them has its own way to the energy efficiency of the complex as a whole. Significant energy losses with wastewater, ventilation emissions and heat losses by animals indicate significant reserves for increasing the coefficient of boenergetic efficiency (Timofeev et al., 2018; Chmil & Oliinyk, 2019).

4. Conclusion

General methodological principles have been developed for the analysis of energy efficiency and environmental safety of agricultural ecological and biotechnical systems, which are based on the definition of the bioenergy efficiency coefficient, the quantitative expression of which is the ratio of energy accumulated in products to the total energy consumption for its production. This makes it possible to model with sufficient accuracy the influence of various factors on the energy and environmental efficiency of the system, to compare and search for energy-saving modes and technologies in order to find and select the most energy efficient ones to increase the energy efficiency of the complex.

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