Bulgarian Chemical Communications, Volume 55, Issue 2 (pp. 108-116) 2023 DOI: 10.34049/bcc.55.2.5560

Sustainable practices in contemporary livestock farming

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Received: March 13, 2023; Revised: June 05, 2023

In recent years, the consumption of dairy and meat products increases worldwide. Alongside this trend, the environmental impact of livestock farms is also increasing. The main problems can be grouped as follows: energy consumption, release of greenhouse gases, clearwater consumption, and discharge of contaminated water. In an effort to reduce the impact of livestock farms, scientists from various fields are developing different solutions to the problems mentioned above. These solutions are highly interconnected, as the output products of one activity often are the input of another. This paper aims to present an analytical overview of the various existing and implemented solutions which help to increase energy independence and create zero-waste dairy production. The provided sustainable practices include: methods for lowering the GHG emissions, approaches for separation and purification of livestock farm waste, biogas producing by anaerobical digestion of organic waste, methods for filtration and purification of waste water. In addition to the ecological effects, the implementation of these practices brings economic profits for livestock farms. The economic efficiency, ecological, and social optimization functions are described.

Keywords: zero-waste production, environmental protection, economic efficiency, livestock farms, risk management.

INTRODUCTION

The increase in dairy and meat products consumption in the last decades leads to the creation of bigger livestock farms. In many cases, the growth of this industry causes significant ecological problems. The managers can weaken the impact on the environment by applying one or more methods for energy independence and zero-waste production of the farm. This paper aims to present an overview of a number of solutions to the environment issues.

By using these practices, the farm managers can also increase economic efficiency, as the consumable expenses decrease and, in some cases, the surplus biogas or energy can be sold to other consumers. Farm management must comply with the parameters of the enterprise when choosing the appropriate solutions to achieve maximum efficiency. It is recommended that processes be modeled in advance to optimize inputs, farm profits, and environmental impact [1, 2].

To deeply understand the environmental issues caused by livestock farms and the practices solving (or mitigating) them, we prepared the present short review. Hence, we conducted our investigation having in mind the following research questions:

RQ 1. What are the most applicable and effective solutions to the environmental problems caused by livestock farms?

RQ 2. What are the economic and social effects of the applied solutions, and how can they be optimized?

Structure of the paper

The second part briefly describes the methodology of the conducted research. The next section presents some practices for lowering the GHG emissions. Then, the applicable methods and process phases for separating of waste are provided. The fifth section explains the implementation of anaerobical digestion of organic waste for biogas production. The most popular approaches for filtration and purification of wastewater are presented in the next section. Optimization according to one of the researched criteria (economic, ecological, or social efficiency) is provided in the seventh section. The paper ends with a brief discussion on the presented solutions regarding the research questions and a conclusion.

Methodology

The literature review was conducted in two steps. Firstly, researchers looked for information about the main environmental problems caused by livestock farms. Some of the searched keywords were “livestock farms” or “dairy farms”, combined with “environmental issues” or “ecological problems”. According to literature sources [3, 4], the most significant are the following issues:

- Release of greenhouse gases, mainly methane, and CO_2, into the atmosphere;
- Energy consumption;
- Clearwater consumption;
- Discharge of contaminated water (effluent) into the environment.

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In the second step, the authors searched for scientific publications on implementing effective solutions for the above-mentioned environmental issues. The authors used as keywords some of those found in the first step, such as "zero-waste production", "environmental protection", "greenhouse gases", "water purification", "economic efficiency", "risk management", and "waste management". The most significant results from the investigation of the selected papers are provided in the next sections.

Greenhouse gases management

One of the major environmental issues of livestock farms is the release of greenhouse gases (GHG) like methane and CO_2 into the atmosphere, which cause global warming. Some of the applied solutions include introducing appropriate feed additives for animals, processing waste (solid and liquid), obtaining [4] and using biofuels, fertilizers, etc. Figure 1 presents a list of activities that increase or decrease the GHG emissions from the farms.

To lower greenhouse gas emissions, livestock farms implement a variety of strategies that include solutions such as changes in feeding, husbandry, and management practices. These changes have an impact on animal health and welfare and should be studied in detail [5].

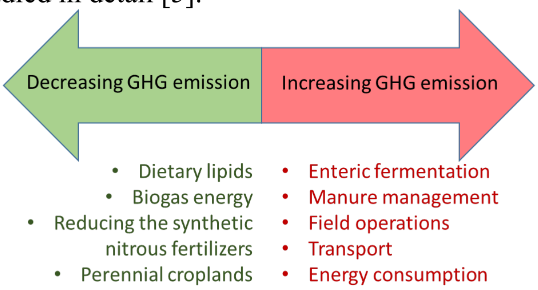

Fig. 1. Greenhouse gas emission in dairy farms [4]

Direct strategies to reduce greenhouse gas emissions (CH_4 and N_2O) from farmyard manure can be classified as reducing rumen methanogenesis, which can be divided into reducing total emissions and reducing emission intensity without directly targeting methanogenesis [6].

Supplementing with antimethanogenic drugs (such as antibiotics that lower methanogen populations) or electron (H^+) acceptors are two methods for lowering methanogenesis [5]. The natural function of the rumen is disrupted by these tactics, which are effective in lowering CH_4 emissions, and their improper use may result in rumen diseases, as well as possible health and welfare issues. The second set of solutions focuses on improving production efficiency to lower GHG emissions while maintaining current levels of production, and it is designed for both ruminants and monogastric. Prominent tactics from this group include boosting feed efficiency or enhancing the herd's health, which operates as profitable tactics by simultaneously enhancing the environment's viability, economic return, or animal welfare as appropriate [5, 7].

Waste management

The livestock farms produce a huge amount of solid waste containing animals' manure, hair, and plant pieces from food or bedding. This matter should be separated according to the particle size and processed further.

The division of the solid matter of animal manure into fractions that can be removed by the main categories of separator or separation process is presented in Table 1.

Table 1. Division of the solid matter of animal manure into fractions [8]

Size, μm	Pollutant
More than 5000	Fibre
Up to 5000	Coarse solids
Up to 1000	Fine solids
Up to 20	Colloidal particles
Up to 1	Dissolved solids

Some of the main problems with biogas slurry are: low concentration, high production volume, and content of very low-molecular-weight (small-molecule) organic pollutants. The risk of groundwater contamination with these low-molecular organic pollutants increases during the process of enrichment (fertigation) of the biogas suspension [9]. The biogas slurry is put through a number of biotechnology processes that have to be modeled to optimize their parameters [10].

Animal hairs, bedding, and larger particles that make up the solid material provide fibrous material from animal manures with a characteristic texture. Following a screening procedure, it can be removed using a variety of separators since the solid material is retained as the slurry passes through a screen [8]. Due in part to the fibrous structure of a lot of the removed material, a fraction of particles that are smaller than the hole size can also be retained. The size of the holes can range from 1 to 5 mm or bigger. However, smaller screens are employed to keep more of the suspended materials [11].

When employed alone, particles with an effective size of about 1 mm are the cut-off for separators. Yet, the concept of particle size is ambiguous due to the physical properties of the fibre. More open screens are frequently required for cow slurries containing significant amounts of straw and associated material in order to ensure adequate separator performance. Particles larger than the size of 5 mm can be defined as a coarse fibre fraction [8].

The applicable technique for particles smaller than 1 mm is based on a sedimentation principle, either by gravity or rapid sedimentation in centrifuges. The settling procedures frequently follow a biological treatment because raw slurry contains several naturally occurring but biodegradable organic surfactants that can prevent flocculation and settling. The separation process depends on the larger density of suspended particles than that of water. However, for animal slurries, this difference is negligible [12]. A preliminary screening procedure can be applied to eliminate the lighter fibrous debris.

Sedimentation processes have a substantial impact on bacteria elimination because they frequently form flocs that are joined to larger particles. This effect can be enhanced by adding flocculants, which also make it possible to remove additional colloidal material using the same technique. The process can be hastened by increasing the temperature, but usually to the same result [8].

Processing for the sludge phase consists of thickening or drying options, with the separated water going back into the feed stream. Filtration may be taken into account for the liquid phase if the amount of suspended materials is small. Due to the creation of a filter cake, which is aided by adding a filter aid like fine sand to the input stream, the retained particle size is likely to be lower than the pore size. A significant portion of the colloidal material may also be removed by filtration, leaving a largely cleared effluent in its place [13]. The impact on the much smaller virus particles will be significantly reduced, but there is no assurance that all bacteria will be eliminated.

The sole separation option for removing the smallest particles and the dissolved stuff itself is based on membranes. Again, filtering is the basic concept, but "crossflow" is frequently the arrangement. This fact suggests that wastewater is forced through the membrane under pressure, squeezing out the clear water (permeate) and leaving a concentrated stream in its place. Only dilute effluents are suitable for such a treatment [8].

Energy management

The energy is needed for various activities that take place on the dairy farm (Figure 2), e.g., milk heating or cooling, keeping the temperature within certain limits, supplying robotic systems, etc.

The author of [3] proposes the following solutions to these issues:

- reducing the volume of milk by condensation;
- using energy produced from farm waste products;
- implementing renewable energy sources such as solar panels.

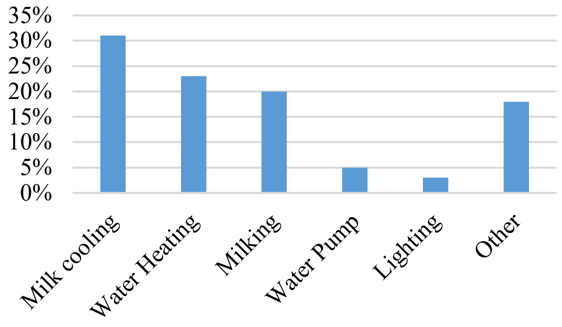

Fig. 2. Energy consumption in dairy farms [3]

Organic waste materials can be processed into useful substances through the application of anaerobic digestion (AD) [14, 15]. AD is a biological process of breaking down organic material in an anoxic environment. In this way, different types of waste can be processed, for example, animal manure, ~~and~~ plant, and industrial waste, and as a result, methane is released [16, 17].

Various models are applied to describe biogas production, most of which are mechanistic and empirical [18, 19]. The main difference between both types of models is their focus. Empirical models are based on mathematical equations to describe the stochastic relationships of various factors and parameters, as well as using real measured process data [20, 21], and mechanistic models focus more on the biological, chemical, and physical laws that relate to the production of biogas. Anaerobic digestion model no. 1 (ADM1) is used mainly for the second option, and it is a dynamic model that includes four stages of anaerobic digestion [22]. ADM1 is a biochemical process in which organic matter is broken down into carbohydrates, lipids, proteins, and inert compounds [19].

A large number of studies have applied an empirical model to predict the rate of biogas production. To investigate the methane production in the anaerobic digestion of swine wastewater, Deng *et al.* [23] use such a mathematical model (Deng model). The purpose of their study is to reveal the impact of organic loading rate (OLR) on methane production. According to their results, the developed model correctly reflects the influence of OLR on the methane production rate. Yang *et al.* [24] modified the Deng model for methane production. The two models are represented by equations (1) and (2):

Deng model [23]:

$$R_p = \frac{R_{p\max}}{1+e^{(K_{LR}-L_r)}} \quad (1)$$

Modified Deng model [24]:

$$R_p = \frac{R_{p\max}}{1+e^{K_D(K_{LR}-L_r)}} \quad , \quad (2)$$

where R_p is the volumetric biogas production rate ($L\ L^{-1}\ d^{-1}$); $R_{p\max}$ is the maximum volumetric biogas production rate ($L\ L^{-1}\ d^{-1}$); L_r is the OLR ($g\ TS\ L^{-1}\ d^{-1}$). K_{LR} is the half-saturation constant ($g\ TS\ L^{-1}\ d^{-1}$), and equals the OLR at one half of the $R_{p\max}$. The index (K_D) denotes the speed of the volumetric methane production rate approaching the maximum as a function of temperature.

Water management

In recent years, two issues related to water management in livestock farms affect the environment:

- *Clearwater consumption.* The consumption of large quantities of drinking water is determined by activities related to the consumption of water by the animals, as well as the cleaning of udders before milking and of premises and milking crates.
- *Discharge of contaminated water* (effluent) into the environment. Many different chemicals are used in livestock farming, which, once processed, are discharged into rivers or lakes, polluting them. Water pollution can be divided into several categories depending on the type of pollutant:
  - o inorganic (minerals, antibiotics, heavy metals, chemicals and other toxic substances);
  - o organic (feces and waste of vegetable and animal origin, oils, lubricants and other petroleum products used by robots and machines in farms);
  - o microbiological (pathogenic bacteria, viruses, some fungi, and parasitic worms).

The solution for both problems can be described in short as reducing the use of clean water by purifying and reusing contaminated water. There are many different methods of water purification, and the choice of one or a combination of them depends on the type of contaminant, degree of contamination, and potential harm. The purification methods and their application are presented in Table 2.

The authors of [25] apply UV disinfection and a 7-stage system with reverse osmosis for the purification of tap water and spring water, implemented in the form of a cascade system.

The reverse osmosis is increasingly used to improve the quality of purified drinking water. This method, however, is not directly applied to fresh water due to the possibility of membrane fouling [33] but is combined with other purification methods.

The authors of [34] propose a short classification of the methods of dairy wastewater treatment, which are mainly divided into biological, natural, physical, and chemical methods (Figure 3).

Table 2. Purification methods and their application

Method	Application	Ref.
Physical purification (mechanical, primary)	coarse substances separation	[25]
Physico-chemical purification	finely suspended particles in water	[25]
Chemical purification	pH adjustment and removal of some solutes	[26]
Biological (secondary) purification	conversion of biological substances from wastewater into biomass	[26]
Filtration	removal of suspended, colloidal and dissolved contaminants	[25]
Disinfection	pathogenic bacteria removal	[26]
Three-layer filter, representing ionosorption column	eliminates highly toxic concentrations of arsenic and chromium from water	[27, 28]
Ion exchange and reverse osmosis	for reducing nitrates in the waters	[29]
Filtration by reverse osmosis, distillation filtration, activated carbon filter for defluorination of aluminum	reducing the content of fluorides in drinking water	[25]
Chlorine compounds	disinfection of water and pipelines	[30, 31]
Microorganisms and the process is accompanied by the consumption of dissolved oxygen in the water	the organic matter is decomposed	[32]

One of the new and promising technologies for wastewater treatment is the separation through membranes, in which organic substances are segregated [35, 36]. This method is based on a pressure difference on both sides of the membrane, which is used as a driving force to separate the different components in the wastewater [37].

In the management of waste manure from pig farms in populated areas and the efficient use of resources, pretreatment by sand filtration (SF) and ultrafiltration (UF) can be applied. Through ultrafiltration and optimization of the pretreatment process for fractionation of biogas suspension, the removal of part of the solid suspended substances and reduction of membrane clogging is achieved.

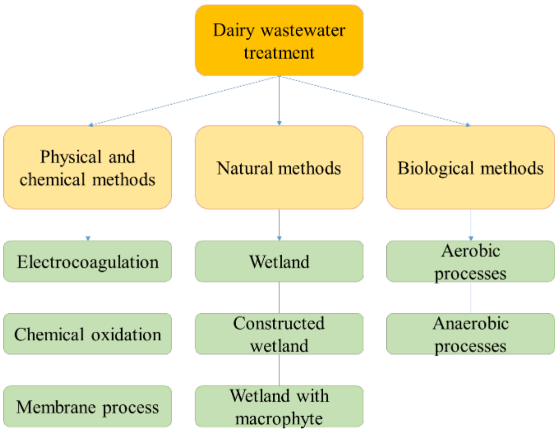

Fig. 3. Methods for dairy wastewater treatment [34]

According to the authors of [37], good ultrafiltration performance can be achieved by prefiltration through a sand column with parameters 100 kDa membrane, and 0.10 MPa transmembrane pressure. Reduction of membrane fouling and improvement of ultrafiltration efficiency is achieved with the reflux of permeate. Their experiments show a higher concentration of organic matter in the effluent without UF compared to those with permeate biochemical treatment. These results clearly show that the UF pretreatment process is suitable to be applied to the treatment of livestock farm wastewater.

Another way to treat wastewater from livestock farms is the Fenton process. The optimal conditions for removing sCOD (dissolved chemical oxygen demand) by this method are described in [38]. Integrating the process with other wastewater treatment methods can increase its potential. For example, after biofiltration, about 91% of sCOD can be removed, and coagulation removes 86% of sCOD [38]. A significant solids load is present in this type of wastewater. Therefore, the application of coagulation before the Fenton process is necessary. The Fenton process does not require complex equipment or hazardous reagents, making it simple and effective.

Optimization of economic, environmental, and social criteria

The optimization can be performed according to one of the following three criteria (Figure 4): economic, ecological, and social efficiency [39]. This section presents the three optimization functions.

The economic efficiency function includes the annual costs associated with the collection of waste mass from animal farms, its transportation, storage, and transformation, and storage of the resulting substances. It also includes the investment costs for the construction of waste processing facilities [40]. This function is defined by equation (3) aiming at its minimization:

Fig. 4. Sustainable development and management concept of Integrated Biogas Supply Chain [39]

$$COST = \sum_{t\in T}(LT_t TDC_t), \qquad (3)$$

where TDC_t is total costs of Integrated Biogas Supply Chain (IBSC) per year, [$ y^{-1}].

The price of the utilized biogas can also be used as a target function. This suggestion is valid for the whole time interval, provided that the regions' needs for this energy carrier are met.

$$COST_{TBG} = \sum_{t\in T}(LT_t TBG_t), \qquad (4)$$

where TBG_t is the total value of biogas used by the regions [$/y].

The criterion that is minimized in ecological optimization is Eco-Indicator 99 [41], which is a standardised approach to evaluating a process, a product, or an activity's global impact. This method can be implemented both in combination with an optimization model and as a standalone tool. The Eco-Indicator 99 which measures the environmental impact of all network operations in terms of the quantity of carbon dioxide equivalent produced over the course of the goods' lifetimes, is used in the proposed environmental impact model.

$$ENV = \sum_{t\in T}(LT_t TEI_t), \quad (5)$$

where TEI_t is overall environmental impact of IBSC [$kg_{CO_2eq.}.d^{-1}$].

Environmental assessments are presented as environmental costs with a monetary equivalent of the environmental impact [40], which is determined by a global warming factor according to formula (6):

$$Cost_{ENV} = C_{CO_2} ENV, \quad (6)$$

where $Cost_{ENV}$, [\$ y^{-1}] are the environmental costs that should be paid, and C_{CO_2} is the coefficient of global warming [\$/$kg_{CO_2eq.}$], which most commonly used value is 0.135 \$/$kg_{CO_2eq.}$ [42].

Social Objective Function: Job creation is used as the social criterion, which includes: manufacturing jobs (direct), new contractor jobs (indirect), and new employees in local services (induced). Next, depending on reliance, the social impact in terms of employment generation is calculated (7).

$$JOB = \sum_{t\in T}(LT_t Job_t), \quad (7)$$

where Job_t is the expected total number of jobs created.

According to [40], finding the values of the below presented decision variables is the problem solution, where the optimization criterion has a minimum value, is the goal of optimization:

- The number, size and location of bioreactors represent the structure of the Supply Chains network.
- Identification of the locations of livestock farms and the waste processing facilities.
- Flows of the transferred farm waste and biogas across the locations.
- Type and amount of the delivery transport for each connection.
- Quantity of GHG emissions produced at each step of the biogas deriving.

The optimization criteria can be divided into economic ($COST$ or $COST_{TBG}$) (3, 4), environmental (ENV or $Cost_{ENV}$) (5, 6) and social (7), looking for sustainability in:

- Minimizing the supply chain's overall logistics costs while accounting for fixed and variable expenses [\$].
- Minimizing the total quantity of GHG emissions, measured in [kg or \$] of carbon dioxide equivalent emissions [$kg_{CO_2eq.}$].
- Calculating the necessary workforce to ensure the sustained implementation of the IBSC's activities [Number of Jobs].

According to mixed integer linear programming [39], the optimization problem for the IBSC design is with a single aim, either environmental, social, or economic, with the remainder being treated as constraints. The supply chain's strategic design incorporates two layers of decision-making: those regarding the construction of the chain's superstructure and those regarding the allocation of farm waste and biogas flows among various locations.

Minimizing the GHG emissions [$kg_{CO_2eq.}$/d]: The goal is to reduce the total annual equivalent GHG emissions caused by the IBSC operation when the optimization problems involve an environmental criterion. This objective function's formulation is based on the overall GHG emissions from the supply chain and other fuels, which are evaluated using the Life Cycle Assessment approach, where emissions are added to each stage of the life cycle.

Minimizing the total annual costs, [\$/y]: The goal is to reduce the total annual costs when an economic criterion is present in the optimization problem. These latter costs comprise the annual totals for capital expenditures, operating expenses, government subsidies, and CO_2 emission costs [39].

Risk management

In addition to optimizing the activities in the livestock farms in terms of environmental, economic and social criteria, it is also necessary to implement economic risk management. The main types of risks, methods of their assessment and an algorithm for their reduction are presented below.

Economic risk for livestock farms is difficult to assess and manage due to multiple uncertainties [43]. Baquet et al. [44] defined five main types of risks related to production, marketing, credit, environment, and personal risk, respectively. Later, Hardaker [45] adds policy-related risk.

There are different methods for risk assessment in agriculture, e.g., "What if?", "Fuzzy matrix", "Scenario analysis", "Cost-benefit analysis" [43], etc.

Boneva and Vatchova [46] outlined the five steps in risk management (Figure 5):

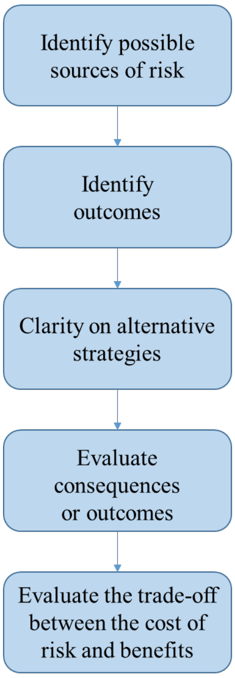

Fig. 5. Steps in risk management

Identify possible sources of risk;

- Identify outcomes that may occur (timing or cost changes);
- Clarity on alternative strategies (change in production plan or new technology);
- Evaluate consequences or outcomes for each possible outcome for each strategy;
- Evaluate the trade-off between the cost of risk and benefits.

Schilling [47] proposes an algorithm for risk reduction that includes the following four steps:

1. Planning and identification of risk-related information (documentation, internal and external circumstances).
2. During the implementation phase, approaches are sought to reduce risk influences.
3. Risk control includes validation, assessment, and search for adequate risk assessment methods.
4. Implement actions related to the improvement and correction of circumstances associated with increased risk.

DISCUSSION AND CONCLUSION

A brief discussion on the findings from this research is provided below with respect to our research questions:

RQ 1. What are the most applicable and effective solutions to the environmental problems caused by livestock farms?

For each of the above-mentioned environmental problems caused by livestock farms, there are a number of solutions. In most cases, the choice of a set of such solutions should be made after thorough research and planning of various aspects such as farm size, number and type of animals kept, long-term goals, and available resources. All the processes that make up such a solution must also be taken into account, since often the output materials from one process are input to another.

RQ 2. What are the economic and social effects of the applied solutions, and how can they be optimized?

Some of the solutions discussed in the article bring economic benefits to the farms that apply them. In order to expand their application, it is necessary to inform farm management about their benefits, as well as support in their implementation by stakeholders.

Other solutions, such as the treatment and reuse of wastewater, are not economically justified but are necessary from the point of view of reducing the impact of livestock farms on the environment. For their wider application, a change in the normative documents and monitoring their compliance is necessary.

The steps to manage risks, as well as an algorithm for their reduction, are presented. Depending on the risk type, different decisions can be made, some of which include choosing less risky technologies, diversification of key suppliers, risk-sharing strategies (including insurance), etc.

The presented sustainable practices would lead to a number of positive effects such as:

- environmental protection;
- zero-waste production;
- energy independence;
- economic efficiency.

Within the assessment of the solutions proposed, the key address ought to be what the goals of the broader farm strategy are. This is often a pivotal beginning point because it will shape the methodology that in turn will empower the choice of the cheapest innovation that's moreover effective.

Acknowledgement: *The research leading to these results has received funding from the Ministry of Education and Science under the National science program INTELLIGENT ANIMAL HUSBANDRY, grant agreement No Д01-62/18.03.2021/.*

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