# CHICKEN MANURE AS CLOSED-LOOP CIRCULAR ECONOMY PRODUCT OF POULTRY INDUSTRY

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**Abstract.** This study explores the integration of chicken manure management into a circular economy framework, highlighting its potential as a renewable resource for organic fertilizer and bioenergy production. The rapid development of poultry farming in the Baltic region has exacerbated the problem of sustainable manure disposal, which has created a need for innovative, cost-effective and environmentally friendly solutions. Through life cycle assessment (LCA), techno-economic analysis, and a review of existing manure treatment technologies, the research evaluates the environmental impact, nutrient recovery efficiency, and economic feasibility of anaerobic digestion and composting systems. The results show that chicken manure, rich in essential nutrients such as nitrogen (N), phosphorus (P) and potassium (K), is effectively converted into high-quality organic fertilizer and renewable biogas. The economic analysis indicates that these technologies become profitable at medium to large farm scales, with a potential net benefit of 285 000 EUR annually for farms processing 5 000 tons of manure, with profitability thresholds identified at around 3 000 laying hens for composting and not less than 10 000 laying hens for biogas production. Furthermore, adopting these technologies contributes to greenhouse gas emission reductions, improved soil quality, and greater energy independence for rural farms. By closing the nutrient and energy loops, this approach aligns with EU sustainability goals and promotes resilient agricultural systems. The findings support the transition toward more circular, low emission farming practices, transforming poultry waste from an environmental liability into a valuable resource.

**Keywords:** circular economy, chicken manure, environment, innovation.

## Introduction

Life cycle assessment (LCA) is a widely recognized and comprehensive tool for systematically evaluating the environmental impacts of products and services. It plays a crucial role in identifying environmentally preferable technologies by assessing and comparing their environmental performance. LCA has been extensively applied to analyse the sustainability of poultry production systems. However, only a few studies have incorporated manure management as a key assessment component [1]. The inclusion of poultry manure processing can substantially affect impact evaluation outcomes. Few LCA studies have focused explicitly on advanced manure management technologies such as pyrolysis, gasification, and anaerobic digestion. Several comparative studies have analysed the environmental performance of various bioconversion methods for valorising agro-industrial residues. For example, Kiss et al. [2] concluded that pyrolysis-based approaches including slow and fast pyrolysis, gasification, hydrothermal liquefaction, hydrothermal carbonization, and supercritical water gasification generally resulted in lower environmental impacts compared to direct land application. Antoniadou et al. [3] and Bruno [1] reported comparable findings regarding gasification versus land disposal.

Additionally, some LCA studies rely on secondary data that may not be specific to the system under analysis, leading to potential inaccuracies in environmental impact estimation. Differences in system boundaries, functional units, and allocation methods can also introduce variability in comparative assessments [4; 5]. Future studies should also explore integrated waste-to-energy solutions, combining anaerobic digestion with nutrient recovery systems, to maximize sustainability benefits [6]. Additionally, advancements in carbon capture technologies and improved manure pretreatment methods could further enhance the environmental efficiency of manure valorisation processes. Addressing these gaps will help policymakers and industry stakeholders make informed decisions regarding sustainable poultry waste management practices, ultimately contributing to climate change mitigation and resource efficiency goals [7]. Farmers commonly manage manure through land applications to enhance crop yields. However, direct application to land can lead to environmental issues, which is why anaerobic digestion is often employed to minimize these risks prior to land application [4]. One significant benefit of anaerobic digestion is the production of renewable biogas, which contains approximately 65% methane. This process not only enhances the fertilizer effect of manure but also eliminates odour, reduces pathogen levels, and lowers greenhouse gas emissions.

Numerous anaerobic digestion biogas plants have been established in various European countries, including Germany, Denmark, Austria, the Netherlands, France, the United Kingdom, Spain, and Italy. During anaerobic digestion, organic matter decomposes, resulting in most nutrients from the solid manure being released into the liquid phase. Consequently, the resulting digested manure, known as digestate, is more environmentally friendly and effective for land application.

Livestock manure should be viewed as a valuable resource rather than waste, as it is rich in nutrients that are biologically available to plants, Figure 1.

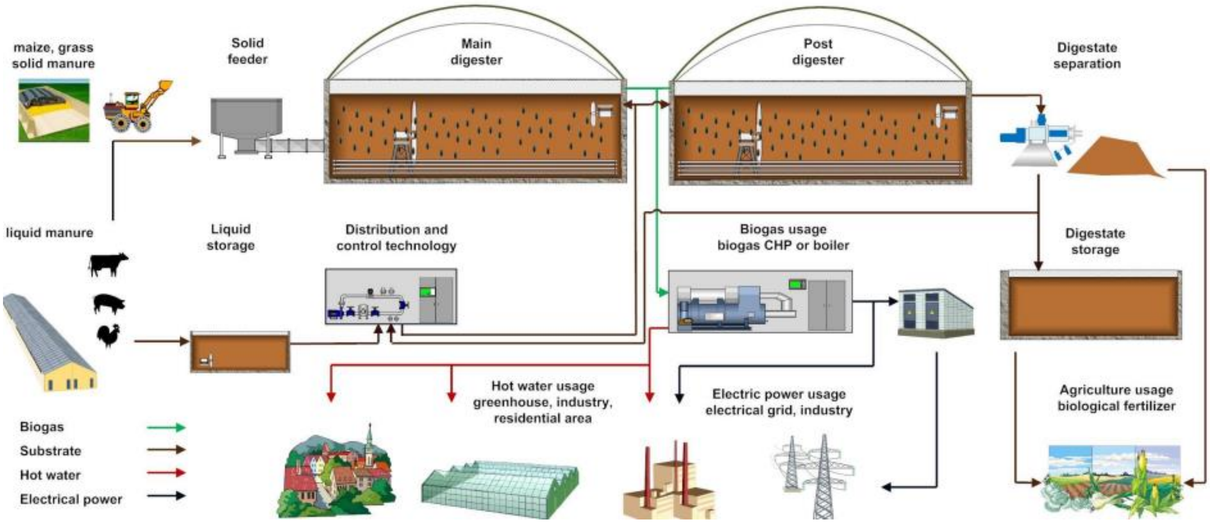


Fig. 1. **Sustainable practices in poultry waste management, circular economy**

The chicken population in the Baltics is growing rapidly, reaching six million individuals by 2024, an increase of 10% since 2018 [8]. Considering that every thousand chickens produce 65 kg of manure per day, and the same number of adult hens – 150 kg [9], the problem of proper disposal of chicken manure is becoming increasingly acute. At the same time, chicken manure and composts based on it are valuable organic fertilizers, rich in nutrients and capable of alkalizing the soil, Table 1.

Chicken manure is a high-quality organic fertilizer that contains approximately 1.63% nitrogen, 1.54% phosphorus ($P_2O_5$), and 0.085% potassium ($K_2O$). It is important to decompose chicken manure before application, as this process eliminates parasites, eggs, and infectious agents while also reducing odour.

Table 1

**Dry matter content manure**

| **Description** | **Dry matter content manure, %** | **Manure, kg. Average per laying hen per year** |
|---|---|---|
| **Rearing layers hen** | | |
| Manure slurry | 20 | 25.0 |
| Manure solid | 55-60 | 10.0 |
| **Layers hen** | | |
| Manure slurry | 20 | 53.0 |
| Manure solid | 60 | 20.0 |

The production of chicken manure organic fertilizer is closely tied to the equipment used in the production line. A complete system typically consists of a fermentation system, drying system, deodorization and dust removal system, pulverizing system, batching system, mixing system, granulation system, screening system, and finished product packing system. The production process for organic chicken manure fertilizer generally includes the following steps: selecting raw materials (such as chicken manure), drying and sterilizing, mixing ingredients, granulating, cooling and screening, metering and sealing, and finally, warehousing the finished product [10].

The nutrients in digestate that are frequently studied include nitrogen (N) and phosphorus (P). The application rate of digestate to land should be consistent with the carrying capacity of the land. It is necessary to seek efficient, cost-effective and environmentally friendly disposal alternatives in intensive farming areas where tons of excess digestate are produced daily. The amounts of major nutrients in the manure produced for a layer hens' unit with 100 000 birds and 6.5 flocks per annum are calculated based on the nutrient concentration values given in the literature, Table 2. It is important to point out that the total amount of nutrients in the poultry manure and the maximum area of agriculture crop that can be grown using these nutrients depend on the nutrient concentration of the manure [11].

Table 2

**Nutrient concentration and the estimated total amount of nutrients in poultry manure for poultry unit with 100 000 birds**

| Nutrients | Concentration, $kg \cdot t^{-1}$ | Total amount, t* | Fertilizer equivalent, t** |
|---|---|---|---|
| Nitrogen | 25.7 | 172 | Urea (374) |
| Phosphorus | 6.7 | 45 | SSP (473) |
| Potassium | 10.1 | 68 | KCI (136) |
| Calcium | 16.2 | 109 | Lime (272) |
| Magnesium | 3.5 | 23 | Dolomite (121) |
| Sulphur | 5.2 | 35 | Gypsum (194) |

* Calculated for 6700 tons of manure

** Urea (46% N); SSP – Single superphosphate (9.5% P); KC – Potassium chloride (50% K); Lime (40% Ca); Dolomite (19% Mg); Gypsum (18% S)

Effective Waste Management: Poultry waste is a significant by-product of the poultry industry, and improper disposal can lead to serious environmental concerns, including water contamination and soil degradation. Bioenergy production provides an efficient solution by converting waste into energy, reducing landfill accumulation and promoting cleaner agricultural operations [12].

Bioenergy production from poultry waste is an innovative and sustainable method for converting organic materials into renewable energy sources, such as poultry manure and processing by-products. This approach aligns with global efforts to reduce dependence on fossil fuels, mitigate environmental pollution, and create sustainable agricultural systems. By leveraging advanced technologies, poultry farms can transform waste into valuable resources, contributing to economic efficiency [13].

Cost Savings and Energy Independence: Producing bioenergy from poultry waste allows farmers and poultry producers to generate electricity and heat, reducing reliance on external energy sources. Over time, this can lead to substantial cost savings, particularly in regions where energy prices are high. Additionally, farms that produce surplus bioenergy can sell excess power back to the grid, creating an additional revenue stream [14].

Promotion of Circular Economy Principles: Bioenergy production supports a closed-loop agricultural system by transforming waste into valuable energy and nutrient-rich by-products. Digestate, a by-product of anaerobic digestion, can be used as a high-quality organic fertilizer, improving soil health and reducing the need for synthetic fertilizers. This approach enhances resource efficiency and aligns with circular economic principles by minimizing waste and maximizing resource recovery [15], [16].

## Materials and methods

The theoretical section is based on an analysis of strategic documents related to the poultry industry production capacity, as well as experimental studies that demonstrate the potential of hen manure as a valuable resource. This analysis utilizes monographic, inductive, and deductive methods. Economic calculations highlight the efficient use of hen manure and illustrate the circular economic benefits of recycling it as a raw material. To conduct the analysis, various gas emission units from the in-house stage were converted into kg.

Economic calculations:

1. Waste disposal costs without processing:

$$C_{\text{disposal}} = Q_{\text{manure}} \times P_{\text{disposal}},$$

2. Revenue from biogas production:

$$Q_{biogas} = Q_{manure} \times V_{biogas},\ E_{biogas} = Q_{biogas} \times W_{biogas},$$

$$R_{biogas} = E_{biogas} \times P_{energy},$$

3. Revenue from organic fertilizer sales:

$$Q_{fertilizer} = Q_{manure} \times K_{yield},\ R_{fertilizer} = Q_{fertilizer} \times P_{fertilizer},$$

4. Total revenue from manure processing:

$$R_{total} = R_{biogas} + R_{fertilizer},$$

5. Net economic effect:

$$E_{net} = R_{total} - C_{processing},$$

6. Cost savings from disposal reduction:

$$S_{savings} = C_{disposal}$$

7. Final total economic effect:

$$E_{final} = E_{net} + S_{savings}$$

where *C* – processing cost, cost of disposal, EUR;
*Q* – manure output per poultry, tons;
*W* – energy content of biogas, kWh·m$^{-3}$;
*E* – amount of biogas, m$^3$;
*P* – price of disposal, EUR;
*R* – revenue from manure processing, EUR;
*E* – economic effect, EUR.

## Results and discussion

Currently, the waste and manure produced by the poultry industry are applied to agricultural land when used correctly. However, pollution and other problems can arise when fertilizers are applied under environmental conditions that do not favour the agronomic use of the nutrients in the manure [9]. The environmental aspect is also a problem: air pollution, unpleasant odours, and the spread of diseases. Chicken manure is considered superior to other animal manures due to its high concentration of macro-nutrients. It has a significant percentage of nitrogen and phosphate [8-9].

Producing granulated poultry manure includes crushing the manure, fermentation, granulation and drying. After fermentation, the mass is exposed to atmospheric oxygen ($O_2$) to stop the methane ($CH_4$) fermentation process and is thickened, isolating the filtrate. Granulation of the manure is carried out simultaneously with drying 55-57 °C by spraying in a fluidized bed and capturing dust in the gases left after granulation [10]. Drying is carried out with flue gases released during the combustion of biogas of the fermentation product. The filtrate obtained during the mass thickening process is heated (humidity of the mass 90-92 wt. temperature 55-57 °C) and used to heat and dilute the original manure before fermentation [13; 17]. The disadvantage of the known method is the low efficiency of using the obtained biogas - a fermentation product that is burned for further drying. In addition, the filtrate returned to the technology for diluting the original manure before fermentation contains nitrogen-containing substances that accumulate in the fermenters over time, which leads to inhibition of the fermentation process. Also, the known technology loses chemicals suitable for biofertilizer in the filtrate returned to the technology [17].

A method for producing organic fertilizer is known, which includes processing animal excrements with mineral acids followed by neutralization, in which animal excrements are mixed with water, treated with mineral acids to a pH of 0.1-2.0, and kept for 2-12 hours at standard temperature and pressure. Then, they are decomposed for 24-60 hours. The resulting liquid phase is separated from undissolved solids, the pH is brought to 5.0-6.2 by adding the primary substance, and after neutralization, the precipitate is separated. Bird droppings, primarily chicken droppings, are used as animal excrement. The animal excrements are mixed with water for 5-6 hours [18]. Coarse foreign bodies are separated from the mixture of animal excrements with water before exposure to mineral acids. The gases formed when mixing animal excrement with water are removed by introducing air into the mixture. Calcium oxide ($CaO$), hydroxide ($OH^-$), or carbonate ($CO_3$) is used as the primary substance. After adding the main substance, the precipitate is separated by centrifugation [19]. The disadvantages of the known method are the loss of the produced biogas and the issues of disposal of volatile substances and unpleasant odours, which have not been resolved since hydrogen sulphide and ammonia formed during the processing of bird droppings are released into the atmosphere. In addition, this technology requires using concentrated sulfuric acid, which is unsafe for workers and the environment [13].

In a universal biogas complex, poultry manure is mixed with water and a liquid fraction. At the same time, the humidity and temperature are brought to the required level, after which the liquid mass of organic waste is fed to the hydrolysis reactor and then to the methane tank. They maintain a given temperature 40-60 °C and acid-base balance while the fermented mass is periodically mixed. Then, the liquid mass of organic waste (chicken manure) is pumped to the hydrolysis reactor, where the humidity is increased, and the *pH* 0,1-2,0 level is controlled. The hydrolysis reactor provides a metered substrate feed to the methane ($CH_4$) tank. The substrate from the methane ($CH_4$) tank is fed to the separator, where the fermentation residues after the methane ($CH_4$) tank are separated into solid and liquid fractions and then fed to the workshop. The solid fraction as a soil restorer can be used in fields or dried, packed in bags, and sold. Biogas passes through the drainage system, is cleaned of moisture, and stabilizes the biogas pressure in the gas holder. Then, the biogas is supplied to consumers. Additionally, it is necessary to create facilities for storing the liquid fraction, the volumes of which are calculated based on seasonal restrictions on the removal of the liquid fraction (fertilizer) to agricultural fields, and removal in containers by special transport in large quantities [14; 20].

The poultry industry is a vital part of agriculture in the Baltic states [21]. Chicken manure, a by-product of this industry, presents both environmental challenges and economic opportunities. Chicken manure as a closed-loop circular economy product in the poultry industry, determines the economically beneficial scale for circular practices, Table 3. On average, a layer hen produces around 0.09-0.15 kg of manure per day. Over a production cycle or year, this adds up significantly depending on the age of the bird. Manure per bird per year 30-40 kg. Value per kg (composted) 0.03-0.10 EUR (market-dependent). Revenue per bird (manure) 1.10-4.00 EUR. Cost per bird to process 1.50-3.00 EUR. Break-even bird count starts around 3 000-5 000 birds. At smaller scales, manual composting might be economical. For biogas, breakeven may be closer to 10 000-20 000 birds, due to higher capital costs. Revenue from manure as compost: 80-100 EUR per ton is common. Biogas/fertilizer savings + potential energy sales: 200 EUR per ton.

Table 3

**Cost-benefit analysis of manure management**

| Farm size (thousand birds) | Manure output, tons per year | Processing method | Processing cost, thousand EUR | Revenue/Savings, thousand EUR | Net benefit, thousand EUR |
|---|---|---|---|---|---|
| 1.0 | 15 | Composting | 1.5 | 1.2 | -0.3 |
| 3.0 | 45 | Composting | 4.0 | 4.5 | 0.5 |
| 10.0 | 150 | Biogas | 25.0 | 30.0 | 5.0 |
| 20.0 | 300 | Biogas | 45.0 | 60.0 | 15.0 |

Implementing circular economy practices in poultry farming, such as composting and biogas production, becomes economically beneficial at certain scales.

- **Composting:** Profitable starting at approximately 3 000 birds.
- **Biogas production:** Profitable beginning around 10 000 birds.

These thresholds are influenced by factors such as processing costs, market prices for by-products, and local regulations. By properly processing this manure, we can lower waste management costs, create additional revenue, and promote environmental sustainability as part of the circular economy. Potential Processing Applications include the following.

- Biogas production: Anaerobic digestion of manure to produce methane.
- Organic fertilizer production: Composting manure to create high-quality fertilizers.
- Animal feed additives: Treating manure for use in feed formulations.

Economic Analysis, Initial Data is summarized below.

- Average manure output per poultry farm: 5 000 tons per year = equivalent to 100 000 laying hens.
- Cost of disposal without processing: 20 EUR per ton.
- Revenue from biogas production: 0.06 EUR per kWh.
- Biogas yield: 70 $m^3$ per ton of manure.
- Energy content of biogas: 10 $kWh \cdot m^{-3}$.
- Cost of organic fertilizer: 50 EUR per ton.
- Fertilizer yield after composting: 0.5 tons per ton of manure.

Waste disposal costs without processing:

$$C_{disposal} = 5\ 000 \times 20 = 100\ 000 \text{ EUR.}$$

Revenue from biogas production:

$$Q_{biogas} = 5\ 000 \times 70 = 350\ 000 \text{m}^3,$$

$$E_{biogas} = 350\ 000 \times 10 = 3\ 500\ 000 \text{ kWh},$$

$$R_{biogas} = 3\ 500\ 000 \times 0.06 = 210\ 000 \text{ EUR.}$$

Revenue from organic fertilizer sales:

$$Q_{fertilizer} = 5\ 000 \times 0.5 = 2\ 500 \text{ tons},$$

$$R_{fertilizer} = 2\ 500 \times 50 \text{ EUR} = 125\ 000 \text{ EUR.}$$

Total revenue from manure processing:

$$R_{total} = 210\ 000 + 125\ 000 = 335\ 000 \text{ EUR.}$$

Assuming total costs for equipment, maintenance, and operations are 150 000 EUR per year.

Net economic effect:

$$E_{net} = 335\ 000\text{-}150{,}000 = 185\ 000 \text{ EUR.}$$

Cost savings from disposal reduction:

$$S_{savings} = C_{disposal},\ S_{savings} = 100\ 000 \text{ EUR.}$$

Final total economic effect:

$$E_{final} = 185\ 000 + 100\ 000 = 285\ 000 \text{ EUR.}$$

Processing 5 000 tons of chicken manure annually can generate a total economic benefit of approximately 285 000 EUR through biogas production, organic fertilizer sales, and waste disposal cost savings. This demonstrates the financial viability of implementing manure recycling technologies in the Baltic states. Reduction of Greenhouse Gas Emissions: Traditional poultry waste disposal methods, such as open-air decomposition or land application, release methane and nitrous oxide, which have a significantly higher global warming potential than $CO_2$. Advanced bioenergy technologies, such as anaerobic digestion, capturing and utilizing methane as an energy source, effectively reduce greenhouse gas emissions and contribute to climate change mitigation efforts.

Technological Advancements in Manure Processing: Ongoing innovations in pyrolysis, gasification, and hydrothermal carbonization are improving the efficiency of poultry waste bioenergy conversion. These advanced technologies offer higher energy yields and reduced emissions compared to traditional methods. Future developments, such as integrating bioenergy systems with carbon capture and storage (CCS), could further enhance the sustainability of poultry waste utilization [18]. Overall, bioenergy production from poultry waste is an essential strategy for achieving environmental sustainability, economic resilience, and energy security in the agricultural sector. By transforming waste into a valuable energy source, poultry producers can reduce operating costs, minimize environmental impacts, and contribute to the transition toward a cleaner and more sustainable energy system.

## Conclusions

1. Chicken manure is a valuable resource in the circular economy model, offering significant potential for nutrient recycling, energy production, and reduction of environmental pollution when properly processed.
2. Anaerobic digestion and composting technologies provide both ecological and economic benefits, especially at scales above 3 000 birds for composting and 10 000 birds for biogas production, making them viable options for mid-to-large-scale poultry farms.
3. Economic analysis shows a net benefit of 285 000 EUR annually from processing 5 000 tons of manure through biogas and organic fertilizer production, illustrating strong financial incentives for adopting circular manure management systems.
4. Environmental benefits – lower $CO_2$ emissions and reduced soil pollution: Recycling poultry waste significantly reduces environmental impact by cutting greenhouse gas emissions, preventing soil and water contamination, and promoting a circular economy.
5. Integration of waste-to-energy systems with nutrient recovery technologies enhances both energy independence and fertilizer efficiency, reinforcing the role of poultry farms as contributors to rural bioeconomy development.

## Author contributions

Conceptualization, V.K.; methodology, V.K. and A.Z.; software, V.K.; validation, V.K. and A.Z; formal analysis, V.K; investigation, V.K., and A.Z.; data curation, V.K. and A.Z.; writing – original draft preparation, V.K.; writing – review and editing, V.K.; visualization, V.K.; project administration, V.K., All authors have read and agreed to the published version of the manuscript.

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