SUSTAINABLE SOLUTIONS FOR POULTRY SLAUGHTERHOUSE WASTEWATER TREATMENT:AN INTEGRATED ANALYSIS AND INDUSTRIAL APPLICATIONS

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ABSTRACT. Poultry slaughterhouses generate large volumes of high-strength wastewater rich in organic matter, fats, oils and grease (FOG), suspended solids, nutrients and pathogens. If inadequately treated, these effluents pose serious risks to surface and groundwater quality, climate (via methane and nitrous oxide emissions) and public health. This paper reviews sustainable technological options for poultry slaughterhouse wastewater (PSW) treatment and proposes an integrated assessment framework combining process performance, life-cycle environmental impact and circular-economy indicators. Recent advances in high-rate anaerobic systems, membrane technologies, electrochemical processes and nature-based solutions are discussed, with emphasis on their capacity to enable water reuse, energy recovery and nutrient valorisation. Industrial and pilot-scale applications, such as integrated expanded granular sludge bed (EGSB)–membrane bioreactor (MBR) systems and the EU Water2REturn project for nutrient recovery, illustrate how multi-stage treatment trains can achieve both regulatory compliance and resource recovery. Remaining challenges include fouling control, energy demand, sludge management, regulatory barriers to reuse and the need for robust economic and life-cycle assessments under real industrial conditions.

Keywords: poultry slaughterhouse wastewater, sustainable treatment, membrane bioreactor, anaerobic digestion, electrocoagulation, life cycle assessment, circular economy, nutrient recovery

1. Introduction

The global poultry industry has expanded rapidly over the last decades, driven by rising demand for affordable animal protein. Poultry slaughterhouses are among the most water-intensive segments of the livestock processing chain and are recognized as significant point sources of wastewater pollution. Poultry slaughterhouse wastewater (PSW) typically contains high concentrations of blood, fat, feathers, proteins and cleaning chemicals, resulting in elevated chemical oxygen demand (COD), biochemical oxygen demand (BOD), suspended solids (SS), nutrients (N and P), pathogens and residual disinfectants.

Traditional treatment approaches based on primary screening, dissolved air flotation (DAF) and conventional aerobic systems can achieve regulatory compliance but often require high energy input, generate large sludge volumes and seldom recover water, energy or nutrients.

In the context of climate change, water scarcity and the EU Green Deal's circular-economy objectives, there is increasing pressure to transition from "linear" end-of-pipe approaches towards integrated, resource-efficient wastewater management strategies. Recent research has explored advanced anaerobic and membrane systems, electrochemical technologies, nutrient recovery and industrial water reuse, often evaluated through life cycle assessment (LCA) and techno-economic analysis.

This paper proposes an integrated, multidisciplinary approach, which aims at the detailed characterization of wastewater from chicken slaughterhouses, the evaluation of the performance of sustainable treatment technologies and the exploration of the possibilities of ecological valorization of the resulting flows. By combining laboratory analysis with testing under industrial conditions and theoretical modeling, the research aims to contribute to the development of a technological framework adapted to the specifics of the Romanian poultry industry, with potential for replication on an international scale.

2.Characteristics and environmental impact of poultry slaughterhouse wastewater

PSW composition varies with slaughter line capacity, cleaning practices and water-saving measures, but typical ranges reported in the literature include COD values of 3,000–10,000 mg/L, BOD of 1,500–5,000 mg/L, suspended solids up to several g/L, FOG concentrations in the hundreds of mg/L and total Kjeldahl nitrogen (TKN) of 50–300 mg/L.

High salinity can arise from the use of brine and disinfectants.

If discharged untreated or inadequately treated, PSW can:

Deplete dissolved oxygen in receiving waters due to high organic loads;

Drive eutrophication via nitrogen and phosphorus release;

Introduce pathogens, pharmaceuticals and disinfectants;

LCA studies of slaughterhouse wastewater management indicate that treatment configuration strongly influences climate change, eutrophication, acidification and energy-use impacts, and that scenarios with advanced treatment and water reuse can significantly reduce overall burdens despite higher operational complexity

3. Conventional treatment schemes and limitations

Traditional PSW treatment typically combines:

1. **Preliminary and primary treatment:** screening, grit removal, fat traps and DAF;
2. **Secondary treatment:** activated sludge or aerated lagoons;
3. **Tertiary treatment (optional):** sand filtration, chlorination or UV disinfection.

While these schemes can meet discharge limits, they present several limitations from a sustainability perspective:

- **High energy demand** for aeration in activated sludge systems;
- **Large sludge production** requiring further treatment and disposal;
- **Limited recovery of value:** organic matter is mostly oxidized to CO_2 rather than converted to biogas; nutrients are removed rather than recovered;
- **Restricted water reuse:** effluent quality may not consistently meet standards for industrial reuse without additional polishing or membrane steps.

These limitations have stimulated the development of more advanced and integrated treatment solutions.

3.1. **Preliminary and Primary Treatment**

Preliminary and primary treatment stages play a critical role in poultry slaughterhouse wastewater (PSW) management by removing coarse solids, fats, oils and grease (FOG), and inorganic materials before biological or advanced treatment processes. Their proper design and operation significantly influence the efficiency, stability and cost-effectiveness of downstream systems such as anaerobic digesters, membrane bioreactors (MBRs) or electrochemical units.

3.1.1. Screening

Screening is the first barrier in the treatment line, designed to remove large solids such as feathers, tissue particles, offal residues, and packaging materials. Fine and coarse screens (typically with openings between 1–10 mm) are used depending on the slaughterhouse load and wastewater characteristics. Automated mechanically cleaned screens are preferred to minimize labor requirements and ensure continuous operation.

Effective screening reduces the risk of clogging in pumps and pipelines, prevents accumulation of solids in equalization tanks and improves the performance of subsequent primary and biological treatment units. Studies show that adequate screening can remove up to 20–30% of total suspended solids (TSS) from PSW and significantly decrease the organic load entering flotation or biological stages.

3.1.2. Grit Removal

Grit removal targets the extraction of dense, inorganic materials such as sand, soil, bone fragments, and other mineral particles introduced during animal handling and cleaning operations. Aerated or vortex-type grit chambers are typically installed to separate particles by settling and to prevent abrasion of pumps, wear of mechanical parts and excessive accumulation in downstream reactors.

Although grit concentration in PSW is lower than in municipal wastewater, even small amounts can have long-term negative impacts on high-rate anaerobic reactors (e.g., EGSB) by reducing effective reactor volume and impairing granule fluidization. Proper grit removal therefore contributes to extending equipment lifespan and maintaining stable reactor hydrodynamics.

3.1.3. Fat Traps (Grease Removal)

FOG concentrations in poultry slaughterhouse effluents can be particularly high due to the presence of skin tissues, residual fats and cleaning chemicals that mobilize lipids. Fat traps or grease interceptors are installed to allow free-floating oils and fats to rise to the surface and be skimmed off, while heavier solids settle at the bottom.

Gravity separation is enhanced by maintaining optimal hydraulic detention times (typically 30–60 minutes), low turbulence and controlled temperature to prevent excessive emulsification. Removing FOG at this stage is essential to avoid operational problems such as pipe blockages, foaming in biological reactors and membrane fouling in MBR systems. Pretreatment to reduce FOG has been shown to improve COD removal efficiencies in anaerobic processes and reduce the need for chemical defoamers and anti-fouling agents.

3.1.4. Dissolved Air Flotation (DAF)

DAF is the most widely used primary treatment technology in slaughterhouse wastewater management. It removes fine suspended solids, colloidal particles and emulsified fats that cannot be separated by simple gravity. The process involves dissolving air under pressure into a portion of the wastewater and then releasing the pressurized stream into the flotation tank, creating microbubbles that attach to particles and lift them to the surface to form a scum layer.

Chemical coagulation–flocculation (using $FeCl_3$, alum, or polymeric flocculants) is often integrated into DAF to improve removal efficiency. When optimized, DAF units can remove:

- 60–90% of FOG
- 50–70% of TSS
- 30–50% of total COD load

The resulting clarified effluent exhibits significantly reduced organic and FOG loads, enhancing the stability of downstream biological treatment units and decreasing membrane fouling rates. Additionally, DAF sludge—rich in lipids and proteins—may be valorized through anaerobic digestion, contributing to circular economy strategies.

Overall Role of Preliminary and Primary Treatment

Together, screening, grit removal, fat trapping and DAF constitute the foundation of an effective PSW treatment train. They ensure:

- Reduction of solid and FOG load entering biological and advanced treatment stages
- Improved process reliability and reduced maintenance costs
- Enhanced biogas yield in anaerobic systems due to more stable reactor operation
- Lower energy consumption and fewer chemical requirements downstream

- Mitigation of membrane fouling and extension of membrane lifespan in MBR or RO systems

By optimizing these initial steps, slaughterhouses can significantly improve overall wastewater treatment performance and support sustainable, integrated resource recovery approaches.

3.2. Secondary Treatment: Activated Sludge and Aerated Lagoons

Secondary treatment processes are designed to biologically degrade the dissolved and colloidal organic matter remaining after preliminary and primary treatment. In poultry slaughterhouse wastewater (PSW), these processes must handle high concentrations of soluble proteins, lipids, and residual fats, as well as nitrogenous compounds derived from blood and tissue residues. Two widely implemented approaches are the **activated sludge process** and **aerated lagoons**, each with distinct operational characteristics, environmental performance, and suitability depending on plant size and regulatory requirements.

3.2.1 Activated Sludge Process

The activated sludge (AS) process remains the most common biological treatment method for industrial and municipal wastewaters due to its adaptability, high removal efficiency, and robust operational control. In the context of PSW, AS systems are typically deployed as conventional continuous-flow reactors, extended aeration systems, or as part of integrated aerobic–anaerobic treatment trains.

Process Description

In an activated sludge system, microorganisms are suspended in the aeration tank where they metabolize organic pollutants under aerobic conditions. Key elements include:

- **Aeration tank:** where oxygen is supplied through mechanical surface aerators or fine-bubble diffusers to sustain microbial activity.
- **Secondary clarifier:** where solids–liquid separation occurs, producing clarified effluent and concentrated sludge.
- **Return activated sludge (RAS):** recycled biomass that maintains high microbial concentrations.
- **Waste activated sludge (WAS):** excess biomass removed periodically to maintain system stability.

Performance and Efficiency

When properly designed and operated, AS systems treating poultry slaughterhouse wastewater typically achieve:

- **BOD removal:** 85–98%
- **COD removal:** 70–90%
- **TN removal:** 40–70% (enhanced through nitrification–denitrification)
- **FOG removal:** moderate, depending on pre-treatment efficiency

The system's ability to achieve nitrification and denitrification is particularly important for meeting stringent nitrogen discharge limits.

Advantages

- High removal of organic pollutants and pathogens
- Good adaptability to load fluctuations
- Easily combined with tertiary treatment (e.g., MBR, sand filtration, disinfection)
- Proven, standardized technology with well-known design guidelines

Limitations

- **High energy demand** for aeration, typically representing 50–70% of total plant energy consumption
- Production of significant amounts of biological sludge requiring downstream handling
- Sensitivity to toxic shocks from cleaning chemicals or disinfectants

- Challenges related to foaming and filamentous bacterial growth, commonly triggered by high lipid content in PSW

To enhance sustainability, some poultry plants integrate activated sludge with anaerobic pre-treatment (e.g., UASB/EGSB), reducing organic load and energy consumption prior to aerobic polishing.

3.2.2 Aerated Lagoons

Aerated lagoons represent a simpler, more cost-effective alternative for secondary treatment, particularly in regions with abundant land availability or for small to medium-sized slaughterhouses. They provide robust, stable operation with minimal mechanical complexity.

Process Description

Aerated lagoons are large earthen or concrete basins where wastewater is retained for long periods (typically 3–20 days). Oxygen is supplied via surface aerators or diffused aeration systems. Depending on depth and mixing patterns, lagoons can operate as:

- **Completely mixed aerated lagoons**
- **Facultative lagoons** (combined aerobic–anaerobic layers)
- **Partial-mix lagoons**, designed for moderate aeration and reduced energy consumption

Biodegradation of organic matter occurs throughout the water column, while suspended solids gradually settle, forming a layer of sludge that is removed periodically.

Performance and Efficiency

Aerated lagoons generally achieve:

- **BOD removal:** 70–90%
- **COD removal:** 50–80%
- **TSS removal:** moderate (enhanced with secondary settling basins)
- **FOG removal:** variable, depending on lagoon design and influent characteristics

Although less efficient than activated sludge, aerated lagoons can meet discharge limits when combined with primary DAF treatment and tertiary polishing.

Advantages

- Low capital cost and low mechanical complexity
- Lower energy consumption compared with activated sludge
- High resilience to hydraulic and organic load fluctuations
- Suitable for remote locations or installations with limited technical staff
- Good buffering capacity for seasonal variations in wastewater characteristics

Limitations

- Require large land areas, making them less suitable for urban or space-constrained sites
- Lower treatment efficiency for nutrients (N, P) without additional processes
- Potential odour generation if aeration is insufficient or the lagoon becomes overloaded
- Sludge accumulation over time, requiring periodic dredging

To improve performance, hybrid lagoon systems incorporating anaerobic pretreatment, baffling, or intermittent aeration have been explored, significantly reducing energy use and improving effluent quality.

3.2.3 Comparative Assessment and Integration in Treatment Trains

The choice between activated sludge and aerated lagoons depends on multiple factors: regulatory requirements, land availability, energy costs, climatic conditions, and the desired level of effluent polishing.

In industrial applications, **activated sludge** is preferred when high effluent quality or reuse is targeted, while **aerated lagoons** remain attractive for low-cost, robust secondary treatment in rural or spacious sites.

Increasingly, poultry slaughterhouses adopt **integrated systems**, such as:

- Anaerobic digestion → Activated sludge
- DAF → Aerated lagoon → Constructed wetland
- UASB/EGSB → Aerated lagoon → MBR polishing

These hybrid configurations balance cost, energy consumption, environmental performance, and resource recovery potential.

3.3. Tertiary Treatment

Tertiary treatment represents the final polishing stage in poultry slaughterhouse wastewater (PSW) management and is essential when stringent discharge standards or industrial water reuse are targeted. While preliminary and secondary processes effectively remove larger solids and biodegradable organic matter, tertiary systems focus on eliminating residual suspended solids, nutrients, pathogens, fats, oils and grease (FOG), and emerging contaminants such as disinfectant residues or microplastics. This stage significantly enhances effluent quality, ensures regulatory compliance, and supports circular-economy strategies through water reclamation and resource recovery.

3.3.1 Filtration Processes

Sand Filtration and Multimedia Filtration

Sand or multimedia filters are commonly employed as a polishing step to remove fine suspended solids and colloids remaining after sedimentation or biological treatment. These filters operate through depth filtration, where particulate matter is trapped within layers of sand, anthracite, garnet or other granular media.

Key performance characteristics include:

- **TSS removal:** 60–90% (depending on influent quality)
- **Turbidity reduction:** effluent levels <5 NTU
- **FOG removal:** minimal, unless combined with coagulation

Backwashing is required periodically to maintain hydraulic conductivity and prevent clogging.

Disc and Drum Filters

For facilities with space constraints or high throughput, disc and drum microscreens (20–200 µm) provide compact, automated filtration with high solids removal efficiency and low water loss.

3.3.2 Membrane Technologies

Membrane-based tertiary treatment offers high removal efficiency for dissolved organics, nutrients, pathogens and salinity, making it the most promising option for wastewater reuse in poultry processing plants.

3.3.2.1 Ultrafiltration (UF)

UF membranes (pore size 0.01–0.1 µm) effectively remove:

- Suspended solids
- Bacteria and most viruses
- Colloidal organics
- Residual FOG

UF is typically used after activated sludge or aerated lagoons to protect downstream nanofiltration (NF) or reverse osmosis (RO) units from fouling.

3.3.2.2 Nanofiltration (NF)

NF membranes provide partial desalination and high removal of:

- Dissolved organic carbon (DOC)
- Multivalent ions such as Ca^{2+} and SO_4^{2-}
- Colour and residual proteins

Effluents treated with NF often meet high-quality reuse standards for cleaning water, but may still require disinfection.

3.3.2.3 Reverse Osmosis (RO)

RO represents the highest-grade membrane treatment, capable of producing near-distilled quality water. It removes:

- Virtually all dissolved solids

- Nitrogen and phosphorus compounds
- Pathogens, viruses, and micro-pollutants

RO is essential when wastewater is reused in critical operations such as boiler feed water, cooling circuits, or high-purity industrial applications.

Limitations of NF/RO:

- High energy consumption
- Concentrate management challenges
- Membrane scaling and fouling, especially with high FOG and hardness levels

Integration with adequate pre-treatment (e.g., DAF, UF) is therefore critical.

3.3.3 Advanced Oxidation Processes (AOPs)

AOPs provide rapid degradation of refractory organic compounds through hydroxyl radical generation. They are used when specific pollutants, colour, or microbial safety require enhanced treatment.

3.3.3.1 UV/H_2O_2

The UV/H_2O_2 process uses ultraviolet light to activate hydrogen peroxide, forming hydroxyl radicals that degrade residual COD, colour, and disinfectant-resistant pathogens.

Benefits include:

- High pathogen removal
- Minimal chemical by-product formation
- Improved biodegradability of effluent

3.3.3.2 Ozonation

Ozone (O_3) is a strong oxidant capable of breaking down complex organic molecules, disinfecting pathogens, and improving effluent colour.

Advantages:

- Effective for viruses, bacteria, and protozoa
- Removes odour and colour
- Enhances UF/NF performance when used as pre-treatment

However, ozone generation requires high energy input and careful safety management.

3.3.3.3 Fenton and Photo-Fenton Processes

Fenton oxidation uses Fe^{2+} and H_2O_2 to degrade recalcitrant organics. When combined with UV light (Photo-Fenton), reaction rates increase significantly.

These processes are particularly effective for:

- Residual proteins and lipids
- COD reduction before membrane filtration
- Colour and odour control

3.3.4 Disinfection

Disinfection is essential when effluent is reused within the plant or discharged into sensitive receiving water bodies. Common disinfection methods include:

3.3.4.1 Chlorination

Chlorine or sodium hypochlorite provide robust microbial control, but may form harmful disinfection by-products (DBPs) when reacting with ammonia or organic matter. Dechlorination may be required before discharge.

3.3.4.2 Ultraviolet (UV) Irradiation

UV disinfection is widely adopted due to its chemical-free nature and effectiveness in inactivating bacteria, viruses, and protozoa. Its efficiency depends on turbidity, UV transmittance, and lamp fouling.

3.3.4.3 Peracetic Acid (PAA)

PAA is increasingly used in the food-processing industry because it:

- Works effectively across a wide pH range
- Does not form harmful DBPs
- Decomposes into harmless by-products (acetic acid, oxygen)

It is well-suited for internal water reuse loops.

3.3.5 Nutrient Removal and Recovery

To meet strict nitrogen and phosphorus discharge limits, tertiary nutrient removal may be required.

3.3.5.1 Nitrification–Denitrification

Biological nutrient removal (BNR) systems can be integrated into the tertiary stage to achieve effluent total nitrogen levels below 10–15 mg/L.

3.3.5.2 Chemical Precipitation

Phosphorus can be removed with alum, ferric chloride, or lime. The resulting sludge may be valorized—after stabilization—as a phosphorus-rich fertilizer.

3.3.5.3 Membrane Concentration and Struvite Recovery

Struvite ($MgNH_4PO_4 \cdot 6H_2O$) precipitation enables simultaneous recovery of nitrogen and phosphorus. This crystalline fertilizer is valuable in agriculture and aligns with circular-economy objectives.

3.3.6 Nature-Based Tertiary Systems

In settings with available land, nature-based solutions (NBS) serve as low-energy polishing alternatives:

- **Constructed wetlands**
- **Vegetated sand filters**
- **Solar-driven lagoons**

These systems provide robust removal of nutrients, pathogens and trace organics while offering landscape and biodiversity benefits, but require larger land areas and careful hydraulic control.

Overall Role of Tertiary Treatment

Tertiary treatment significantly enhances effluent quality by ensuring:

- Removal of residual organic matter and suspended solids
- Reduction of nitrogen, phosphorus and emerging contaminants
- Effective pathogen control for water reuse
- Stable performance of downstream membrane systems
- Compliance with stringent environmental and reuse standards
- Opportunities for nutrient recovery and circular economy integration

Properly designed tertiary systems allow poultry slaughterhouses to transition from traditional end-of-pipe treatment towards **resource-efficient, integrated wastewater management**, enabling safer discharge and sustainable water reuse within the plant.

4. Experimental scheme proposal for introducing vegetable/fruit peels into the wastewater treatment process in a slaughterhouse

1. Purpose

o To evaluate the efficiency of processed peels (dried, shredded peels, activated biochar) in removing BOD_5, COD, fats and nutrients from pre-treated slaughterhouse wastewater.

2. Materials and pretreatment

o Source: mixed peels (citrus, banana, potato, carrot) collected from the food industry / slaughterhouse.

o Preprocessing: washing → drying at 60-80° C → shredding to 1-5 mm.

o Adsorbent variants:

a) unprocessed shredded peels,

b) biochar (carbonization at 400–600°C, without chemical activation),

c) activated biochar (activation with KOH or H_3PO_4, followed by washing).

o Initial characterization: specific surface area (BET), pH, density, preliminary adsorption capacity (batch tests).

3. Installation

o Installation: vertical adsorption column (e.g. Ø 0.1–0.2 m, adsorbent bed height 0.5–1.0 m) in the branch after the primary clarifier.

o Layer: sand screed (10–20 cm) + active layer of biochar/shells (30–80 cm).

o Pilot flow: set for HRT/contact of 15–60 minutes (depending on concentrations).

o Operation: constant flow (pump), load wave control (buffer via equalization tank).

4. Analytical methods and sampling points

o Points: inlet before clarifier, clarifier outlet, adsorbent column outlet, final effluent (after MBR/disinfection).

o Parameters: pH, BOD_5 (5 days), COD-Cr, TSS, fats/oils, $N\text{-}NH_4^+$, N-total, P-total, coliforms, heavy metals.

o Batch (basin) tests for adsorption isotherms (Langmuir, Freundlich) and kinetics (pseudo-first order, pseudo-second order).

5. Regeneration and management

o Regeneration options: backwashing, thermal regeneration or chemical regeneration (e.g. HCl/NaOH) — economic evaluation.

o Alternatives: composting or anaerobic digestion of saturated adsorbent → biogas + digestate.

6. Performance measurements

o Efficiency (%) of BOD_5, COD, TSS, fats, N and P reduction.

o Adsorption capacity (mg pollutant/g adsorbent).

o Functional duration to saturation (m^3 treated/kg adsorbent).

o Estimated costs (raw material, pretreatment, replacement/regeneration) vs. commercial adsorbents (activated carbon).

7. Indicative design parameters (simplified calculation example)

• Pilot flow rate: 1 m^3/h.

• Inlet BOD_5 concentration: 2500 mg/L.

• Target BOD_5 reduction at column outlet: 40–60% (depending on adsorbent).

• Hypothetical adsorption capacity for shell biochar: 50–150 mg BOD_5 / g (values highly dependent on pretreatment — must be determined experimentally).

• Adsorbent bed required for 24 h operation without regeneration: calculation = (Flow rate * BOD_5 load * 24h * target reduction) / (adsorbent capacity) → e.g. (1 m^3/h * 2500 mg/L * 24 h * 0.5) / 100 mg/g ≈ 300 g → exemplary — real values probably much higher; must be validated experimentally.

Note: capacity values are indicative;

Possible risks and challenges

· Variability of shell nature → inconsistent performance.

· Interference with fats and colloidal materials → column blockage/clogging.

Pretreatment required (drying/ carbonization) which adds energy costs.

· Chemical regeneration may produce additional waste.

Next practical steps

1. Conduct batch tests for three adsorbent variants (unprocessed, biochar, activated) to determine isotherms and real capacities.

2. Establish a column pilot for 3-6 months, with continuous monitoring.

3. Evaluate economic integration: comparison with activated carbon and other pretreatments.

4. Publish results and recommend scaling/implementation.

5. Conclusions

Poultry slaughterhouse wastewater is a challenging but valuable resource stream. Conventional treatment systems, while capable of meeting discharge standards, often fail to exploit the latent energy and nutrient content and may exhibit high energy use and sludge production.

Recent advances in high-rate anaerobic digestion, membrane bioreactors, electrochemical processes and nature-based solutions offer robust, sustainable alternatives, especially when configured as integrated multi-stage treatment trains. These systems can deliver:

- High removal of organic matter, nutrients and pathogens;
- Positive or near-neutral energy balances through biogas recovery;
- High-quality effluents suitable for internal water reuse or fertigation;
- Recovery of nutrients into marketable fertilizer products.

Life-cycle and techno-economic assessments generally support the environmental and economic viability of such sustainable solutions, particularly under tightening water and climate policies. However, widespread implementation will depend on overcoming technical challenges (e.g., fouling, process stability), securing investment, harmonizing regulations and ensuring social acceptance of resource recovery practices.

Overall, an integrated, circular-economy approach to PSW treatment—combining advanced treatment technologies, LCA-based decision tools and industrial symbiosis—represents a promising pathway for transforming poultry slaughterhouses from pollution sources into hubs of resource recovery and sustainable water management.

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