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Sustainable Strategies for Broiler Waste Management: Insights from Stakeholder Prioritization in Thailand

Senaka Bandara[1], Chatchawan Chaichana[2,3]

1) *Division of Mechanical Engineering Technology, Institute of Technology University of Moratuwa, Homagama, Sri Lanka*
2) *Renewable Energy and Energy Conservation Laboratory, Department of Mechanical Engineering, Faculty of Engineering, Chiang Mai University, Chiang Mai 50200, Thailand*
3) *Department of Mechanical Engineering, Faculty of Engineering, Chiang Mai University, Chiang Mai 50200, Thailand*

*) *Corresponding Author: c.chaichana@eng.cmu.ac.th*

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Abstract— **Thailand's significant contribution to the global chicken meat industry demands the adoption of sustainable broiler waste management practices, particularly as countries worldwide strive to implement strict policies aimed at reducing emissions from agricultural products. This study employed the Analytic Hierarchy Process (AHP) to analyze diverse stakeholder perceptions regarding the adoption of these practices, utilizing a multi-criteria decision-making approach. Experts prioritized environmental concerns (0.4386), emphasizing sustainability, while farm owners prioritized economic factors (0.5987), reflecting profit-driven motives. Subcriteria analysis highlighted the significance of financial aspects, with "Capital cost" attaining the highest weight (26.05%), followed by environmental concerns like "Climate change" (11.05%). Technical feasibility and societal considerations received moderate prioritization. Stakeholder preferences for waste management methods further highlighted divergent perspectives, with experts favoring gasification for its environmental benefits, while owners prioritized land application for its cost-effectiveness. Composting emerged as a balanced choice. These findings emphasize the importance of considering diverse criteria in waste management decision-making, highlighting the need for comprehensive approaches to ensure sustainability in Thailand's broiler waste management practices.**

Keywords— Broiler waste management, Sustainable agriculture, Climate change, AHP

I. Introduction

Thailand is a leading chicken meat producer and exporter in the world [1]. The chicken meat production of the country is forecasted to grow further in the future with increasing demand for the most popular source of animal protein. Consequently, more broiler waste will be generated that needs to be managed in a sustainable manner. In general broiler litter includes bird excreta, bedding material used in chicken houses, feathers, and waste feed [2]. The daily output of manure from a chicken is estimated to range from 80 to 100 grams, accounting for approximately 3-4% of its body weight [3]. Numerous factors can influence the rate of litter production and its nutrient content. These factors encompass the type and quantity of bedding material, the number of birds in a broiler house, stocking density, feed composition, housing type, ventilation rates, waste management practices, drinker management, bird health, and the age of birds [4]. Hence, estimations of broiler litter production and the nutritional composition featured in published works tend to exhibit variations. Different bedding materials are used worldwide in the broiler industry, including wood shavings, straw, and rice husks. Farmers typically select bedding materials based on factors such as price and availability [5]. The choice of bedding material is crucial as it absorbs moisture and facilitates its subsequent release, while also providing insulation and cushioning for the birds against the floor. Rice husk is the primary bedding material used in Thailand's broiler industry, with the standard practice being the removal of broiler litter from the broiler houses at the end of each production cycle. Majority of Thai broiler farmers find selling the removed broiler litter to fertilizer companies to be a lucrative source of additional income. Due to its high levels of nitrogen, phosphorus, and potassium, untreated chicken manure is frequently used as organic fertilizer in agricultural fields [6]. However, overuse of this can result in environmental pollution, including air quality degradation, heightened greenhouse gas (GHG) emissions, the buildup of toxic trace metals, eutrophication in water bodies, soil acidification, and increased nutrient losses, particularly nitrogen and phosphorus from soil due to leaching, erosion, and runoff, often resulting from inadequate consideration of crops' nutrient needs [7]. The strong odor emitted by untreated chicken manure attracts flies and pests, promoting the spread of pathogens and antibiotic-resistant bacteria, which poses a clear risk to human health [8]. These factors highlight the importance of exploring alternatives for managing broiler litter in a sustainable manner.

Composting livestock manure is a well-established method for organic waste management, involving microbial decomposition to produce a stabilized soil amendment. The process, influenced by environmental factors and waste parameters, progresses through mesophilic, thermophilic, cooling, and maturation phases [9]. Amendments such as sawdust and biochar enhance composting efficiency and fertility [10], [11]. While composting offers benefits like waste volume reduction and improved soil fertility, challenges include cost, equipment, and time requirements. Specific to broiler litter, optimal composting conditions involve low moisture, ammonia levels, and specific aeration methods. Research indicates composting effectively reduces antibiotic resistant genes and enteric bacteria, with temperature and pH impacting antibiotic breakdown [12], [13]. However, heavy metals may persist, posing potential risks upon land application.

Anaerobic digestion is another technology widely researched in the field of organic waste management [14]. It can produce biogas and organic fertilizer while reducing GHG emissions. The substantial biomethane potential of chicken manure makes it a viable feedstock for energy production, with an estimated yield of around 0.5 m^3 of biogas containing approximately 58% methane per kilogram of organic matter [15]. However, the high nitrogen levels present in chicken manure impede methane production [16]. Proposed solutions to counteract this limitation include, the addition of trace elements, co-digestion with nitrogen-deficient materials, and in-situ ammonia removal techniques [17]. It must be noted that effectively managing the substantial digestate output is crucial for ensuring the sustainability of anaerobic digestion and mitigating potential environmental issues [18].

As per regulations set forth by the European Parliament and Council, utilizing chicken manure as an on-site fuel is recognized as a promising energy source [19]. An Irish study evaluated the environmental impact of three scenarios: (1) using poultry manure for land spreading and heating broiler houses with LPG; (2) burning poultry manure for heating broiler houses; and (3) utilizing poultry manure for steam and electricity generation [20]. The results indicated that poultry manure combustion could result in a decrease of up to 95% in LPG usage, along with reductions in eutrophication (26%-32%) and acidification potential (31%-40%). It has been reported that the co-combustion of poultry litter with biomass can lead to reductions in emissions of NO_x and CO, as well as lower levels of particulate matter (PM) [21]. However, direct combustion of manure is notably inefficient when compared to pyrolysis and gasification processes [22].

Pyrolysis of chicken manure, which is another thermochemical process involves the thermal decomposition of biomass without oxygen, resulting in the production of biochar, bio-oil, and syngas products [23]. This valorization of biowaste provides a significant contribution to the circular economy [24]. High-temperature pyrolysis has been shown to decrease the bioavailability, leachability, and environmental risk associated with heavy metals present in chicken manure, thereby enhancing its safety for soil application [25], [26]. Hossain et al. examined biochar from chicken manure pyrolysis, noting their high nitrogen and potassium content, indicating their potential as soil nutrient sources [27]. In a comparative analysis of chicken manure pyrolysis and air gasification, Burra et al. observed that achieving higher energy yields from pyrolysis requires very high temperatures, making it less economical, while the cumulative energy yields from gasification were found to be superior to pyrolysis [28].

Conversely, gasification involves the thermochemical conversion of organic materials mainly into syngas and solid biochar. This process is highly efficient for generating power, heat, as well as producing hydrogen and second-generation biofuels [29]. Belgiorno et al. concluded in their study that gasification stands out as the most economical and efficient method for disposing of chicken manure while also generating energy, highlighting its ability to yield high energy output with minimal emissions compared to other disposal methods [30]. Compared to incineration and combustion processes, gasification emit significantly lower levels of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) compounds [31]. Joseph et al. discovered that the char obtained from gasifying broiler litter retained about 92% of the original nitrogen content, indicating a minimal release of NO_x during the process [32]. In a study by Wu et al., it was found that gasification of feedlot manure results in significantly lower net greenhouse gas emissions (-643 kg $CO_{2\text{-}eq}$ per ton of dry manure) compared to land application (119 kg $CO_{2\text{-}eq}$ per ton of dry manure), highlighting its potential for reducing environmental impacts [33]. This was mainly due to the positive effects of syngas and biochar on the environment. The co-gasification of chicken manure and wood pellets revealed that the calorific value of the syngas increases proportionally with the amount of woody biomass in the mixture, while also demonstrating that pelletized chicken manure generates higher-quality syngas compared to dried shredded chicken manure [34]. Torretta et al. investigated poultry manure gasification and its energy yield, noting the relatively low tar yield compared to what would be expected from pyrolysis, which typically exceeds 27% [35], [36]. Research conducted in the UK examined the environmental impacts of producing electricity through the gasification of poultry waste in a small-scale integrated gasification combined cycle (IGCC) facility. In contrast to electricity derived from traditional fossil fuels, this method resulted in a carbon footprint reduction of 91%-96% and a decrease in primary energy demand of 98%-99% [37]. In addition, hydrothermal liquefaction (HTL), and wet torrefaction can be seen as promising technologies for treating chicken litter [38], [39].

Anaerobic digestion faces challenges with high nitrogen levels impeding methane production and requires management of substantial digestate output, combustion has inefficiencies and more emissions, pyrolysis requires very high temperatures for high energy yields and produces a high amount of unstable bio-oil that needs further treatment. These limitations make composting, and gasification more viable for broiler waste management in Thai farming. The objective of this study was to identify a sustainable broiler waste management method for Thailand using perspectives of different stakeholders. To achieve this goal, the study compared land application, composting, and gasification as potential waste management options.

The Analytical Hierarchy Process (AHP) has been widely used across various studies as a multi-criteria decision-making (MCDM) tool to determine the most suitable waste management method in numerous studies. This method has been applied in diverse contexts such as plastic waste management, household waste management, treatment of municipal solid waste (MSW), and selection of hazardous waste disposal sites [40]–[43]. These studies emphasize the significance of considering multiple criteria in decision-making processes related to waste management. By providing a structured approach to prioritize and rank alternatives, AHP facilitates stakeholders in making informed decisions for sustainable and efficient waste management practices. Additionally, the results can be useful in identifying prevailing challenges and gaps in the respective area. The authors adopted a comprehensive approach by evaluating the problem based on environmental, economic, technical, and social criteria and underlying subcriteria using the AHP.

II. Materials and Methods

The AHP introduced by Saaty in 1980 is a powerful decision-making tool that efficiently handles both qualitative and quantitative criteria involved in MCDM processes. The AHP is structured hierarchically, allowing for the systematic consideration of various options in decision-making scenarios [44]. The application of this method entails three steps. In the initial phase of the AHP, problem identification and structuring involve defining the decision problem and organizing it into a hierarchical structure. This is achieved via decomposing the main goal, which is at the top level of the hierarchy, into criteria and further subdividing these into sub-criteria and alternatives until reaching the lowest level.

In the second step, a questionnaire is designed according to the model and circulated among the respondents (users, managers, experts etc.) to gather their opinions through pairwise comparisons on the relative importance or preference between different elements within the decision hierarchy. The respondents assign numerical values, typically on a scale from 1 to 9 according to Saaty's scale for pairwise comparison, to express the strength of preference or importance of one element over another (TABLE I). The last step is synthesizing the assessments made across the different tiers of the hierarchy to obtain priority rankings (weights) [45].

TABLE I. Saaty's Scale For Pairwise Comparison

Relative intensity	Definition
1	Equal importance/preference
3	Moderate importance/preference
5	Strong importance/preference
7	Very Strong importance/preference
9	Extreme importance/preference
2,4,6,8	Intermediate values of the judgment

The process begins by constructing a pairwise comparison matrix(A) using the judgement data. Matrix A is a square matrix of dimensions n x n, where n represents the number of evaluation criteria under consideration [46]. Next, the weighted sums of the elements in the columns are computed for each row of the comparison matrix. This leads to obtaining a normalized matrix by dividing each element in every row of the comparison matrix by the total column weight obtained. Finally, a priority vector (W) is generated by averaging each row of the normalized matrix [47]. To maintain consistency in the judgements provided by experts, a consistency check is carried out for each matrix by calculating the consistency ratio (CR).

Initially, the eigenvalue (λ_{max}) is determined using equation (1).

$$(A - \lambda_{max} I)W = 0 \quad (1)$$

Then the consistency index (CI) is calculated by the equation (2).

$$CI = {(\lambda_{max} - n)}/{n - 1} \quad (2)$$

Subsequently, the CI is divided by the standard correction value known as the Random Index (RI), to get the CR.

$$CR = {CI}/{RI} \quad (3)$$

Judgements are deemed consistent when the CR value is less than 10%. Once the consistency of judgments has been verified, the next step involves synthesizing the judgments by aggregating weights using the hierarchy to establish the combined priorities of each alternative.

A. *AHP Hierarchy Construction*

The AHP model of this study has four levels. At the top level, the goal of the study problem is to select an appropriate broiler waste management method for broiler farms in Thailand. The main criteria considered for selecting the broiler waste management method are outlined at the second level. Among the limited number of AHP studies conducted on livestock manure management practices, it has been noted that two studies conducted in the Netherlands and Cyprus have integrated environmental, economic, and social criteria [48], [49]. However, several AHP investigations focusing on MSW management, industrial waste management, e-waste management, and waste-to-energy technologies have also incorporated technical criteria, as these studies assessed various waste management technologies [50]–[52]. Therefore, environmental, economic, technical, and social criteria were selected for this study. Moreover, the third level of the hierarchy focuses on sub-criteria under each criterion. These sub-criteria were chosen following an extensive literature review and consultation with experts. **Error! Reference source not found.** provides a description of the criteria and sub-criteria utilized in constructing the AHP model.

TABLE II. MAIN CRITERIA AND SUBCRITERIA

Main Criteria	Subcriteria	Description
Environmental	Climate change	The potential impact on climate patterns and global temperature rise.
	Acidification	The potential for increased acidity in soil, water, or ecosystems.
	Eutrophication	The risk of nutrient over-enrichment in water bodies, causing algae blooms.
	Water use	The quantity of water required and potential strain on water resources.
	Land use	Land requirements and potential impact on biodiversity and ecosystems.
Economic	Capital cost	Initial investment required for implementing the waste management solution.
	Operating cost	Ongoing expenses associated with maintaining and operating the solution.
	Revenue generation	Potential income streams or cost-saving opportunities from the solution.
Technical	Technical feasibility	The practicality and technical viability of implementing the solution.
	Ease of implementation	The simplicity and practicality of deploying the solution.
	Technological robustness	The solution's resilience and reliability under various conditions.
Social	Health and safety	Potential risks to human health and safety associated with the solution.
	Public acceptance	The level of societal support and acceptance for the proposed solution.
	Community benefits	Potential positive impacts on local communities and stakeholders.

Finally, the alternatives considered for this assessment to achieve the study's goal are presented at the fourth level, including land application, composting, and gasification. Fig. 1 illustrates the hierarchical model used in this AHP analysis.

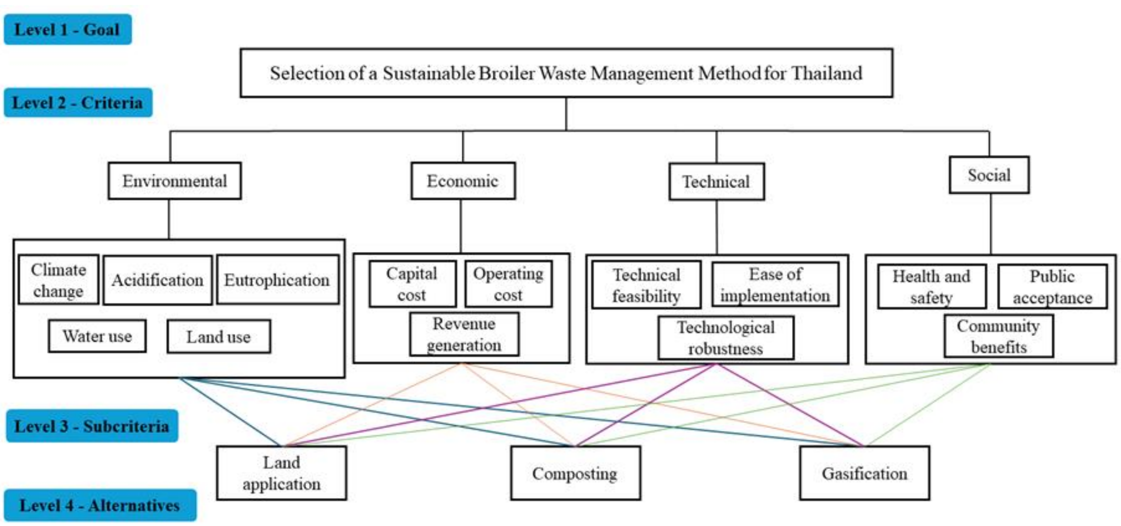

Fig. 1 AHP hierarchical model

B. Pair-wise Comparison

A questionnaire containing quantitative questions was formulated to gather pairwise comparisons of elements within the hierarchical AHP model [53], [54]. A total of 8 respondents from two stakeholder groups were selected for this study. Those included 5 educators/researchers, comprising 2 from energy engineering, 2 from agriculture engineering, and 1 from environmental engineering, and 3 farm owners. Stakeholder judgments were gathered in accordance with Saaty's scale for each comparison, assigning scores to each criterion and sub-criterion being compared to achieve the goal of the study.

C. Synthesizing Judgements

The collected data was processed using the Super Decisions Software (version 3.2), the only free educational software that implements AHP. This software was developed by the team led by Thomas Saaty, the founder of the AHP method. Results were obtained individually for each of the eight individuals before calculating the average priorities for each criterion, sub-criterion, and alternative for the two stakeholder groups.

III. Results and Discussion

The synthesis of pairwise comparisons yielded distinct rankings of the main criteria with respect to the overall goal as depicted by Fig. 2. Experts assigned the highest priority to environmental criteria (0.4386), emphasizing the importance of sustainability and eco-friendly practices. In contrast, farm owners prioritized economic criterion (0.5987), reflecting profit-driven motives. While the technical criterion received relatively low scores, social criterion gained the lowest priority ranking of about 0.1 from both groups. This indicated a potential gap in awareness or understanding of the broader implications of technical advancements and social considerations in waste management practices in broiler farming. Addressing this gap through targeted education and stakeholder engagement efforts could contribute to a more comprehensive and sustainable approach to broiler waste management in Thailand.

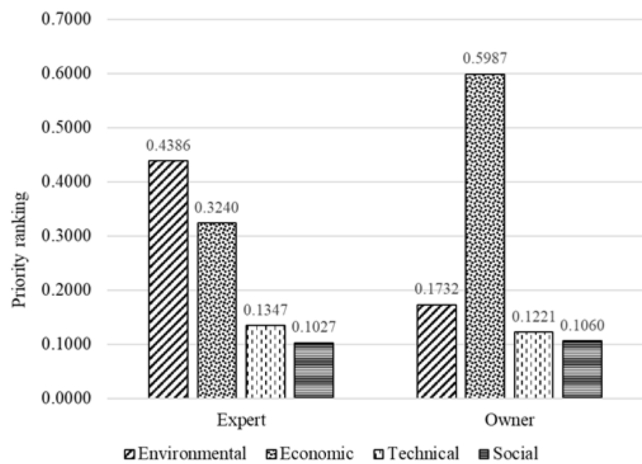

Fig. 2 Priority rankings of main criteria

The relative weights of subcriteria provide valuable insights into stakeholder perceptions regarding the key priorities in selecting a broiler waste management method (Fig. 3). Notably, “Capital cost” emerged as the most significant consideration with a substantial weight of 26.05%, followed by “Revenue generation” (12.50%), highlighting the significance of financial aspects in decision-making. This prioritization reflected stakeholders' keen focus on minimizing upfront investment, ensuring long-term cost-effectiveness within the industry, and identifying waste management solutions with substantial economic returns. Environmental concerns were also highlighted, with “Climate change” ranking prominently at 11.05%, suggesting a recognition of the urgent need to address GHG emissions associated with broiler waste. Technical considerations such as “Technical feasibility” (4.66%) and "Technological robustness" (3.55%) received moderate prioritization, emphasizing the importance of practical and reliable waste management technologies. However, social considerations like “Public acceptance” (2.70%) and “Community benefits” (2.66%) received lower priority, suggesting the need for increased recognition of their societal impacts.

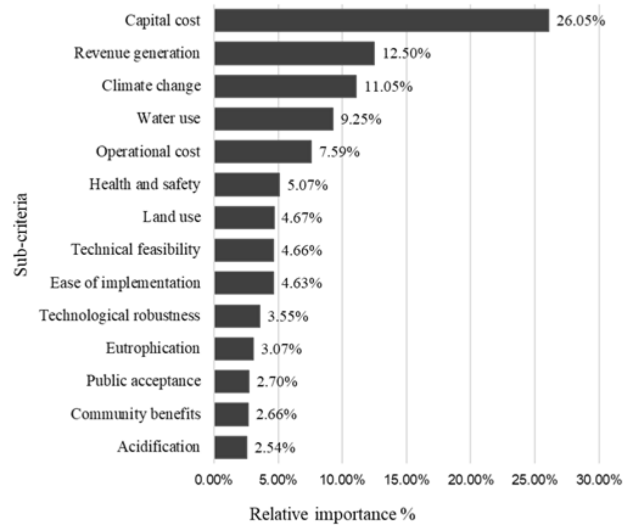

Fig. 3 Priority rankings of subcriteria

The results of the alternatives, namely land application, composting, and gasification, as perceived by both stakeholder groups, experts, and farm owners, offered valuable insights into their preferences and perceptions regarding broiler waste management methods (Fig. 4). From expert feedback, gasification emerged as the favored option, with a considerable percentage of 46.92%. This preference aligns with their likely emphasis on considerations such as environmental sustainability and technological robustness given gasification’s ability to convert organic waste into useful energy products while minimizing environmental impact.

Interestingly, gasification ranks substantially lower among owners compared to experts, with a percentage of 22.41%. Owners showed a clear preference for land application, with a commanding percentage of 50.31%. This disparity reflected owners’ concerns regarding the practicality and feasibility of implementing gasification technology, as well as potential uncertainties surrounding its operational and financial implications.

Additionally, this could suggest that owners may prioritize solutions that offer quick benefits or align more closely with their existing operational practices and resource capabilities. Composting stands out as a notable choice for both stakeholder groups, with comparable percentages between experts (27.23%) and owners (27.28%).

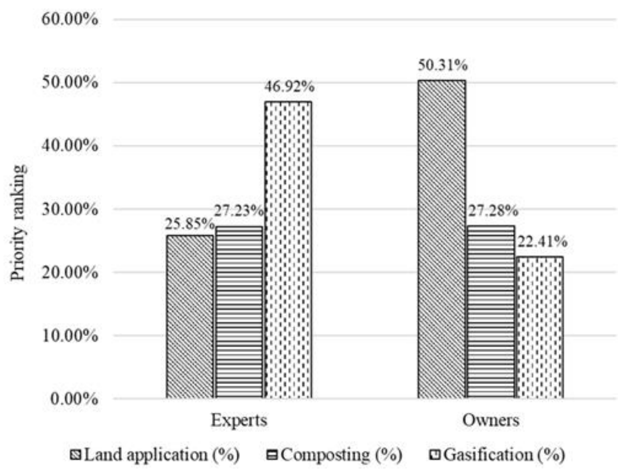

Fig. 4 Alternative rankings

The multi-criteria performance results for the three broiler waste management practices provided valuable perspectives into their overall effectiveness across environmental, economic, technical, and social dimensions (Fig. 5). Gasification demonstrated superior performance in both environmental and social criteria, scoring highest in these areas (0.466 and 0.448 respectively. Similarly, land application excelled in economic (0.494) and technical (0.413) criteria, while falling short in environmental and social criteria. Composting showed balanced performance across all four criteria, with moderate scores.

These observations emphasized the need for a comprehensive approach that balances environmental sustainability, economic viability, technical feasibility, and social acceptability in broiler waste management decision-making.

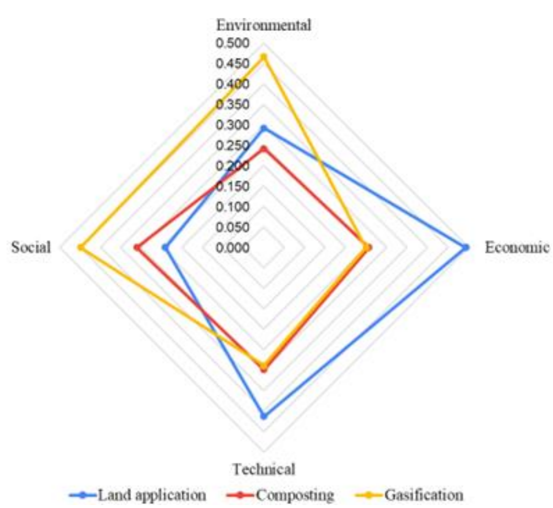

Fig. 5 Multi-criteria performance of alternatives

IV. Conclusions

Thailand's substantial role in the global chicken meat industry highlights the importance of implementing sustainable broiler waste management practices. With projections indicating an increase in chicken meat production in the country, the generation of broiler litter is expected to rise, necessitating efficient waste management strategies. This study provides a fresh outlook on the utilization of Analytic Hierarchy Process (AHP) for selecting sustainable broiler waste management methods based on stakeholder feedback.

The analysis of stakeholder preferences revealed a notable disparity between experts and owners in their priorities, reflecting the multifaceted nature of broiler waste management decision-making. While experts advocate for advanced technologies such as gasification to address environmental concerns and promote innovation, owners tend to prioritize simpler, cost-effective solutions such as land application that align with immediate operational needs. This disagreement underlines the complexity of balancing environmental sustainability, economic viability, technological feasibility, and social concerns in waste management decision-making.

Several strategies can be considered to address this disparity and promote alignment between stakeholder perspectives. Firstly, the need to improve the understanding of sustainable waste management among farm owners. Implementing educational workshops and knowledge transfer initiatives, facilitated by research institutions or universities, could significantly contribute to this goal. Moreover, organizing forums where stakeholder groups, including relevant government agencies and policymakers, can convene to discuss strategies and solutions may further enhance collaboration and collective action.

Additionally, policy interventions and incentive mechanisms can be implemented to promote the adoption of sustainable waste management practices. This may include providing financial incentives or subsidies for the adoption of innovative technologies, implementing regulatory frameworks to encourage compliance with environmental standards, and supporting research and development initiatives to advance waste management technologies.

In conclusion, by strengthening collaboration, implementing supportive policies, and raising awareness, Thailand can pave the way towards more sustainable and resilient broiler waste management practices, ensuring the long-term sustainability of both the poultry industry and the environment. The utilization of the AHP offered a novel and insightful perspective on stakeholder judgments, offering a structured framework for evaluating diverse criteria and helping informed decision-making in pursuit of sustainable waste management practices.

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