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Assessing the Sustainability of Broiler Waste Management Strategies in Thailand through Analytical Hierarchy Process Analysis

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***Abstract*— This study addresses the imperative of sustainable broiler waste management in Thailand, a significant global producer and exporter of broiler meat. Utilizing an Analytic Hierarchy Process (AHP) analysis, it systematically evaluates three waste management strategies – direct land application, composting, and gasification – across environmental, economic, technical, and social criteria with 15 sub-criteria. Climate change is identified as the top priority sub-criterion, followed closely by water use. Gasification emerges as the most preferred option with 52.6% preference, outperforming composting (24.8%) and direct land application (22.6%). A comprehensive analysis reveals gasification's superior environmental and social performance, while direct land application demonstrates economic efficacy. Composting exhibits a well-rounded performance across all criteria. Pioneering the AHP model in broiler waste management, this study offers policymakers crucial insights for formulating sustainable long-term policies to address this pressing issue.**

***Keywords*— AHP analysis, Broiler water management, Climate change, Sustainable agriculture**

I. INTRODUCTION

The broiler chicken industry has become a vital contributor to the global food supply by providing an affordable source of protein to a growing population. The broiler production will experience significant growth in the future, as the demand for chicken meat continues to rise. According to the latest statistics, Thailand is the seventh largest chicken meat producer with approximately 3.425 MT, and fourth largest chicken meat exporter with 1.035 MT per year [1]. Nevertheless, with this expansion, the environmental footprint associated with broiler production is also expected to rise. The amount of broiler waste generated will be increased with increasing poultry meat production. Broiler waste, also known as broiler litter, is a mixture of bedding material and poultry manure that can have serious environmental consequences if not managed properly.

Broiler waste management is a challenging issue that requires the consideration of multiple factors, including environmental, economic, technical, and social performance. The environmental performance of broiler waste management technologies involves the mitigation of greenhouse gas (GHG) emissions and the prevention of contamination of soil and water bodies [2]. The evaluation of economic performance entails analyzing both the capital and operational expenditures, as well as the potential income generated through energy production or the sale of byproducts. The assessment of technical performance encompasses the analysis of the reliability, feasibility, and scaling of each solution [3]. The evaluation of the effect of a given technology on the surrounding community and the workers engaged in its operation is an integral aspect of social performance.

Direct land application, composting, and gasification are the most prevalent techniques for managing broiler waste [4]. Direct land application involves applying broiler waste directly to agricultural land, thereby providing fertilizer for crops and reducing the amount of waste that must be dumped. Composting is the controlled degradation of broiler waste into stabilized fertilizer, and gasification is the thermochemical conversion of broiler waste into a synthesis gas that can be used to produce energy. This paper aims select sustainable broiler waste management technology for the broiler industry of Thailand by evaluating the environmental, economic, technical, and social performance using multi-criteria decision analysis (MCDA) of direct land application, composting, and gasification.

II. BROILER WASTE MANAGEMENT TECHNOLOGIES

The handling of broiler waste has become a major concern in the poultry industry, as it presents numerous environmental, economic, technical, and social challenges. The rapid expansion of the poultry sector due to the rising global demand for chicken meat has led to an increase in broiler generated waste. The improper management of this waste can result in soil and water pollution, GHG emissions, and the spread of disease, among many other environmental and health problems. To overcome these challenges, different broiler waste management methods, including direct land application, composting, and gasification have been investigated.

A. Direct land application

Direct land application includes applying broiler waste as fertilizer directly to agricultural land. Although this method is simple and inexpensive, it can also result in soil and water contamination and the emission of GHGs. Furthermore, the high nitrogen and phosphorous levels in broiler excreta can cause an imbalance in soil nutrient levels, thereby lowering croup output and affecting the ecosystem.

Heavy rains can easily wash away poultry litter from the soil into surrounding water streams, and lakes. Nutrient pollution of surface water results in eutrophication, which is the excessive proliferation of algae that consumes aquatic nutrients and oxygen while obstructing sunlight. Nitrogen in poultry litter can be converted to ammonia and nitrates. Elevated concentrations of nitrate in drinking water can cause cancer, respiratory disease, abortion in livestock, and methemoglobinemia, also widely recognized as the "blue baby disease", in infants [5].

Furthermore, chicken litter is contaminated with bacterial pathogens, antibiotics, pesticides, heavy metals, and growth hormones, all of which have detrimental effects on human and environmental health [6]. Chicken litter may contain highly pathogenic bacteria that are harmful to humans, animals, and the environment. These pathogens can spread vertically from parent flocks to offspring, as well as horizontally via contaminated feed, equipment, and the mobilization of farm pests and personnel. The application of contaminated chicken litter on crops poses a threat to food safety because it can compromise plants, fruits, and water systems. Some of these pathogenic bacteria are also resistant to antibiotics, which makes treatment difficult and expensive. Salmonella is a zoonotic pathogen often found in broiler litter. Salmonellosis outbreaks have shown multidrug-resistant strains, making treatment challenging. This suggests that antimicrobials may be being misused in small, and medium sized broiler farms. Hence, broiler chicken litter should be monitored routinely to lessen these bacteria from spreading [7]. In commercial broiler production, antibiotics are routinely administered at low doses for disease prevention and growth promotion [8]. Pesticides are also incorporated in the poultry diets to eliminate insects in bedding material [9]. These antibiotics and pesticides are typically chlorinated. When this antibiotics-loaded and pesticide-laden chicken litter is applied to agricultural land, some of these substances may leach into groundwater and other freshwater bodies, potentially contaminating them. This could cause environmental and health problems. Heavy metals are introduced to broiler chicken feeds as minerals to prevent diseases, and to obtain better feed conversion efficiency for enhancing weight gain [10]. Metal concentrations in manure often reflect the metal concentrations in chicken feed. Therefore, the high metal content of soils treated with broiler litter can enhance the flow of metals to surface waters through runoff [11]. The levels of Cadmium (Cd) and Lead (Pb) in chicken feed in Asia, North, and South America are alarmingly high, at 782.8 mg Cd/kg and 722.4 mg Pb/kg, respectively. The feed ingredients (pre-mix) contain even higher levels of Cd (1094 mg/kg) and Arsenic (3190 mg/kg), which exceeds the maximum permissible levels (MPLs) of 0.5 mg/kg for Cd and Pb, and 2.0 mg/kg for As, recommended by the EU (European Union) Standard Agency. Excessive levels of Arsenic, Cadmium, Mercury, Lead, and Cobalt in drinking water can have adverse health effects. As can cause malnutrition and a variety of cancers, including those of the upper gastrointestinal tract, reproductive system, lungs, and skin. Cd is carcinogenic and can cause harm to the kidneys, liver, and brain. Hg and Pb can result in fatal brain damage, whilst Co can induce infertility. Hormones such as 17β-estradiol and testosterone are employed as growth enhancers in the poultry industry [12]. These hormones can last for more than two years after excretion. These hormones reach surface water sources via runoff and affect the reproductive capabilities of aquatic creatures like fish.

B. Composting

Composting has been a popular method for managing livestock manure among farmers for a very long time. Composting involves the biological decomposition of waste into a stabilized product that can be used as an organic soil amendment. A substantial amount of heat is liberated due to various metabolic activities of microorganisms which causes notable temperature fluctuations during the decomposition of organic matter. The mesophilic phase, thermophilic phase, mesophilic phase II (cooling), and maturation phase are the four temperature-based stages of composting [13], [14]. To promote aerobic microbial decomposition and stabilization of organic matter in conditions that expedite the development of thermophilic temperatures, manure is often mixed with other organic matter and carbon-rich additives throughout the composting process. The composting process is influenced by environmental factors including temperature, moisture content, pH, and aeration, and organic waste parameters including carbon-to-nitrogen (C/N) ratio, particle size, and nutrient content. Chicken manure can be characterized by its low C/N ratio, high moisture content, low porosity, and high pH. The addition of sawdust, wood chips and rice husk enhance the C/N ratio and porosity while minimizing the moisture level [15], [16]. It has been observed that co-composting biochar with organic matter accelerates composting and produces a substrate with higher fertility and carbon sequestration capability [17]. Composting has the advantage of reducing the volume of waste, improving soil fertility, and reducing GHG emissions. However, composting can also be expensive, requiring specialized equipment and facilities, as well as a significant amount of time and management.

Composting broiler litter presents numerous obstacles which include reducing operational costs and managing moisture level, NH_3-N losses, and odors. Field research and economic assessment reveal that composting broiler litter with little or no amendment at 40% or less moisture is most cost-effective. Keener et al. suggested that in-vessel composting with forced aeration, mechanical turning, and a high ambient NH_3 level (>160 ppm) is much suited for producing low-moisture, high-N compost from broiler litter [18]. Subirats et al. investigated the efficacy of composting in removing antibiotic resistance genes (ARGs) and enteric bacteria in broiler litter. Results of this study revealed that composting drastically reduces the number of enteric bacteria, particularly those that are resistant to antibiotics. It was also deduced that fertilization with composted litter, as opposed to direct land application, reduces the risk of transmitting antibiotic-resistant genes and enteric bacteria to soil and crops [19]. Similar research was carried out by Chu et al. to determine the accumulation of several heavy metals and the behavior of two antibiotics (Doxycycline and Gatifloxacin) after 35 days of aerobic composting of broiler litter. Redundancy analysis (RDA) confirmed that physio-chemical parameters (primarily temperature and pH) affected antibiotic concentration during composting. Thus, increasing composting temperature, extending high-temperature exposure, or increasing pH should facilitate antibiotic breakdown. However, heavy metals remained highly concentrated in the final composted product, which could potentially be transmitted to humans if applied as organic fertilizer [20].

C. *Gasification*

Gasification is a thermochemical conversion of carbonaceous feedstock in a gasifying medium that produces a combustible synthesis gas (syngas). The primary components of the syngas are CO, H_2, N_2, CO_2, certain hydrocarbons, and traces of H_2S, NH_3, ash and tar [21]. Drying, devolatilization (pyrolysis), combustion and reduction are the four main stages that make up gasification. Water is removed by heat during the drying phase (100-150 °C), biochar is produced via the pyrolysis process (200-500 °C) in an oxygen - free environment, air is added to burn and crack tars during combustion (800-1200 °C), and finally biochar is converted into a combustible gas during the reduction phase (650-900 °C) [22]. This strategy is suitable for managing broiler waste as it significantly reduces waste volume and GHG emissions while producing a valuable energy product and a carbon-rich byproduct.

Animal waste gasification may pose challenges due to its high moisture and ash content, and lower heating values. Hence, co-gasification with fossil fuels or plant-origin biomass is considered a viable alternative [23]. Joseph et al. explored the thermo-chemical characteristics of gasification and the utilization of cellulose-based materials as feedstock [24]. The primary goal was to investigate the thermal properties of cellulosic waste from poultry farms, that included chicken manure and wood shavings. It was discovered that this method minimizes chicken litter transportation costs and associated emissions, while the electricity produced by the gasification process can be used to power farm operations. The biochar obtained from the gasification of litter from this study retained around 92% of the Nitrogen, indicating that this technique will produce low NO_X emissions. It was also determined that having more wood shavings in litter can recover more energy as its CV is around 26% greater than chicken manure. The co-gasification of chicken manure and wood pellets (Pinus sylvestris) showed that the calorific value of the syngas increases with the proportion of woody biomass in the mixture. In addition, it was observed that pelletized chicken manure produced syngas of higher quality compared to dried shredded chicken manure [25]. The co-gasification of chicken manure and petcoke was studied to achieve sustainable waste management. The catalytic effect of chicken manure ash on petcoke gasification was evident from the improved carbon conversion and higher CO percentage in the syngas [26].

In a study by Wu et al., life cycle assessment (LCA) was used to investigate the environmental effects of manure management practices, including land application and gasification. The results indicated that for one ton of dry feedlot manure, the net GHG emissions were 119 kg $CO_{2\text{-eq}}$ for land application and -643 kg $CO_{2\text{-eq}}$ for gasification. It was concluded that gasification of feedlot manure offers greater potential as a method for decreasing GHG emissions compared to land application. This is primarily due to the effects of syngas and biochar on the environment[27]. The procedure of selecting a suitable technology for managing broiler waste may require the evaluation of several factors, such as environmental, economic, technical, and social aspects. Using an appropriate MCDA methodology is imperative due to numerous criteria.

III. Methodology

A. *Analytic hierarchy process*

MCDA is a subfield of Operations Research that employs a range of methods, such as Analytic Hierarchy Process (AHP), TOPSIS, Analytic Network Process (ANP), and ELECTRE etc. to facilitate decision making in the presence of multiple, usually conflicting, criteria[28], [29]. AHP which is developed by Thomas L. Saaty in the 1970s is one of the most widely used MCDA techniques by decision makers across various domains to solve different decision-making issues[30]. This method enables decision makers to simplify an intricate problem by breaking it down into criteria, sub-criteria, and alternatives. Decision makers can then rank the available alternatives by conducting comprehensive pairwise comparisons at each level. The methodology comprises several crucial steps, which include [31] :

a. Organize the decision problem in a hierarchical structure comprising levels that include goal at the highest level, followed by criteria, sub-criteria, and alternatives at the lowest level.
b. Conduct pair-wise comparisons for each element at the corresponding level.
c. Determine the maximum eigenvalue, consistency index (CI), consistency ratio (CR), and normalized eigenvector for each comparison matrix to obtain priority weights for each criterion/ alternative.
d. Synthesize judgments across various levels of hierarchy to create a comprehensive priority ranking for alternatives.

The AHP method uses a consistency check mechanism to eliminate any incoherent evaluations by experts, which is deemed as a beneficial aspect. It is recommended to maintain the CR below 0.10, as values above this threshold may indicate notable inconsistencies in the expert judgments, thereby compromising the reliability of the AHP analysis [30]. The goal of this study is to identify the most sustainable broiler waste management technology to implement in broiler farms in Thailand. The objectives are to minimize environmental impact, maximize economic viability, and ensure technical feasibility and social acceptability. To construct the AHP model, a comprehensive search of the literature was conducted to gather as much relevant information as possible. A questionnaire is formulated based on the developed model and distributed among the respective experts for pairwise comparison. Pairwise comparison is a fundamental step in the AHP to determine the relative importance of different criteria or alternatives. The decision-makers compare each criterion or alternative to every other criterion or alternative using Saaty's scale, which ranges from 1 to 9 as shown in **Error! Reference source not found.**. Super Decisions software was used in this study to construct the hierarchy network, compare criteria, sub-criteria, and alternatives based on expert feedback, and determine the optimal alternative.

TABLE I. EXTENTS OF PARAMETERS IN THE INVESTIGATION.

Relative intensity	Definition	Explanation
1	Of equal value	i is equally important to j
3	Slightly more value	i is slightly more important than j
5	Essential or strong value	i is strongly more important than j
7	Very strong value	i is very strongly more important than j
9	Extreme value	i is extremely more important than j
2,4,6,8	Intermediate values between two adjacent judgments	-

B. Criteria, sub-criteria selection

AHP permits a structured and systematic evaluation of multiple criteria and sub-criteria to assess the sustainability of waste management approaches. This section outlines the process of selecting the criteria and sub-criteria used for the AHP analysis. The first step is to determine the main criteria used to evaluate the sustainability of broiler waste management methods. These criteria should include the key factors that contribute to sustainability. Among the limited number of AHP studies conducted on livestock manure management practices, it has been identified that two studies carried out in the Netherlands and Cyprus have incorporated environmental, economic, and social criteria [32], [33]. However, several AHP studies conducted on municipal solid waste (MSW) management and industrial waste management methods have included the technical criteria as well [34], [35]. Based on a comprehensive review of the literature and expert consultation, it was determined that a waste management system is sustainable when it is environmentally friendly, economically viable, technically feasible, and socially acceptable.

After establishing the main criteria, it is important to define the specific sub-criteria that will be used to further assess each main criterion. The sub-criteria should be selected considering their relevance, measurability, and significance in the evaluation of sustainability. Lijó et al. considered the environmental aspects climate change, terrestrial acidification, marine eutrophication, water and land use, while their economic criteria entailed capital cost, operational cost, and revenue generated from recovered energy and byproducts [32]. In the study conducted by Azahari et al. in Malaysia, the technical criteria encompassed considerations such as technical expertise, and the availability of appropriate technologies and facilities. Additionally, within the social criteria, the study included elements such as social acceptance, stakeholder involvement, and health-related factors [36]. In this study, the selection of sub-criteria was made by considering all the aforementioned information, as well as specific considerations pertaining to the current broiler waste management practices in Thailand. Climate change, marine eutrophication, and terrestrial acidification were chosen as sub-criteria for the environment criteria. These are three of the environmental impact categories considered in Life Cycle Assessment (LCA) studies. Capital cost, operational cost, and potential revenue generation were selected as sub-criteria of the economic criterion. Infrastructure, and equipment needed for successful implementation, technical expertise needed to carry out the operations, and process parameters are the sub-criteria for the technical criterion. Furthermore, the social criterion comprises sub-criteria such as health and safety concerns, public acceptance, and employment opportunities created. A summary of the criteria and sub-criteria chosen for this study are tabulated in **Error! Reference source not found.**.

TABLE II. OVERVIEW OF CRITERIA AND SUB-CRITERIA.

Criteria	Sub-criteria	Comments	References
Environmental	Climate change	Weighted sum of the life cycle emissions of greenhouse gases, mainly CO_2, CH_4, N_2O	[17], [32], [37]
	Eutrophication (terrestrial)	Nutrient enrichment of aquatic bodies in terms of nitrogen	[5], [11], [32], [34], [38]
	Acidification	Atmospheric deposition of acidifying inorganic substances that cause acidity change of the soil	[5], [17], [19], [32], [38]
	Water use	Evaluation of the amount of water required or affected by a waste	[39], [40]

		management method, considering potential usage and environmental implications	
	Land use	Assessment of the impact of a waste management method on the utilization and alteration of land resources	[41], [42]
Economic	Capital cost	Acquisition costs of land, building, and equipment etc.	[32], [34], [37]
	Operating cost	Includes maintenance and operational costs	[32], [34], [37], [38]
	Revenue generation	Revenue potential through factors such as market demand, cost savings, resource recovery, product sales, and potential revenue streams	[32], [34], [37]
Technical	Technical feasibility	Practicality of implementing a waste management method based on available technology and infrastructure	[36]
	Ease of implementation	Logistical simplicity and practicality in executing a waste management method	[34], [43], [44]
	Technological robustness	Reliability and durability of the technology used in waste management to withstand challenges	[45]
	Regulatory compliance	Alignment of a waste management method with relevant environmental and safety regulations	[46], [47]
Social	Health and safety	Well-being and safety of workers and the neighboring community	[48]–[50]
	Public acceptance	Community acceptance of technologies and environmental awareness	[28], [37], [38]
	Community benefits	Number of jobs created to support operation	[28], [37], [38], [50]

C. Stakeholder analysis

In an AHP study, obtaining feedback from experts holds significant importance in the decision-making process. In this context, experts are defined as individuals who possess a high level of specialized knowledge and expertise in the specific subject area that is being assessed [51]. The experts should possess a comprehensive understanding of broiler waste management practices, including their environmental, economic, technical, and social implications. The experts may include academics and researchers, industry professionals, government officials and policy experts, and technology providers and consultants. A diverse group of experts from diverse backgrounds can provide a well-rounded evaluation of the broiler waste management methods under consideration in the AHP study. In this preliminary investigation, the analysis was conducted by using the expertise of an academic researcher.

D. Application of AHP for waste management assessment

AHP was applied to determine the most effective composting technology for the composting facility at the National University of Malaysia [34]. The researchers conducted interviews with experts to facilitate pairwise comparisons. The analysis was conducted using the Super Decisions software. The results indicated that the technical criterion had the highest importance score (0.5000), followed by the environmental (0.2517), economic (0.1941), and social (0.0542) criteria. The overall synthesis showed that windrow composting is more effective than in-vessel composting. Kurbatova and Abu-Qdais conducted an AHP analysis to select the most appropriate waste to energy (WTE) technology for the Moscow region in Russia [50]. The developed AHP model consisted of four levels, which assessed four WTE technologies using three criteria and nine sub-criteria. Environmental and health criterion emerged as the most important criterion with a priority weight of 0.729 and landfill biogas plant was the preferred WTE technology option. Fogarassy et al. used a similar approach to identify an effective MSW strategy for the Ho Chi Minh City, Vietnam [52]. However, they reported the subjective nature of the AHP method may pose potential limitations in the assessment process. This is due to the heavy reliance of the AHP on the expertise and knowledge of the decision-makers, that could bring in personal biases or preconceived notions.

An investigation in Cyprus employed a combined LCA and AHP approach to compare environmental performance and sustainability of different livestock waste management options [32]. Due to the subjective nature of the process, a sensitivity analysis was conducted to ascertain the impact of criterion weighting on the outcomes. Gebrezgabher et al. developed an AHP based decision-making tool to address the livestock manure management problems in the Netherlands [33]. It was concluded that the suggested methodology assists decision-makers and policymakers develop policies that promote economically, socially, and environmentally sustainable manure management systems.

The AHP has been employed in multiple waste management investigations conducted in Thailand to determine appropriate waste management techniques, based on various criteria. A study was conducted utilizing the AHP methodology to propose appropriate MSW technologies for the city of Bangkok [37]. The results of the study indicated the following order of priority rankings for broiler waste management techniques: composting, anaerobic digestion, gasification, landfill gas, refuse-derived fuel, and incineration. Another case study was conducted by Boonkanit and Kantharos to aid decision-making in prioritizing and selecting an industrial waste management method for the Map Ta Phut Industrial Estate, Thailand [35]. This investigation was based on the criteria of technology, economics, environment, laws, and regulations. The researchers recommended that forthcoming studies should consider additional crucial factors, such as social aspects. However, a thorough survey of the literature revealed a lack of research on the application of AHP to determine the most sustainable broiler waste management method. Therefore, this study aimed to address this gap by developing an AHP model specifically tailored for the evaluation of broiler waste management techniques.

IV. Result and Discussion

The evaluative framework utilized in this study establishes a distinct hierarchy among criteria pertinent to broiler waste management. It attributes primary importance to environmental considerations (weight: 0.53), followed by technical (0.22), economic (0.19), and social criteria (0.06), as depicted in Fig. 1.

Subsequently, within the realm of sub-criteria, "Climate Change" emerges as the most substantial determinant with a weight of 0.2272, underscoring its paramount significance within the overarching environmental criterion. In contrast, "Community Benefits" and "Public Acceptance" exhibit comparatively lower weights at 0.0129 and 0.0147, respectively, indicative of their relatively diminished influence within the social criterion. This discernible disparity accentuates the disparate weighting assigned to distinct facets, elucidated further in Fig. 2, which delineates the distribution of weights among sub-criteria.

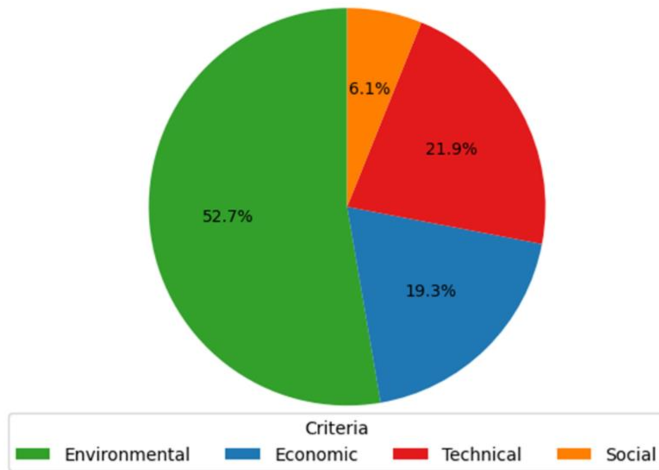

Fig. 1. Priority rankings based on criteria.

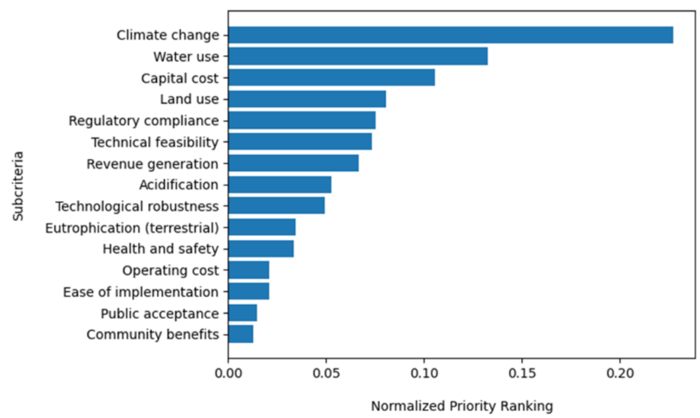

Fig. 2. Normalized priority rankings of sub-criteria.

Here, the pronounced significance of climate change in broiler waste management is evident, accentuating its pivotal role, whereas the roles of community benefits and public acceptance appear more marginal in the evaluative schema.

The comprehensive evaluation of broiler waste management methods underscores gasification as the preeminent strategy, securing the highest ranking at 0.526, indicative of its superior performance (Fig. 3). Following closely is composting with a ranking of 0.248, while direct land application trails with the lowest ranking at 0.226. These findings accentuate the efficacy of gasification as the most favored method, demonstrating its holistic performance across environmental, economic, technical, and social criteria when juxtaposed against alternative methodologies.

Further elucidating the performance of each method across primary criteria, a visual representation is provided in Fig. 4 through a web chart. A meticulous analysis reveals the outstanding environmental and social performance of gasification, with direct land application showcasing notable economic effectiveness. Additionally, composting is distinguished by its well-balanced performance across all four criteria. This nuanced examination offers a comprehensive understanding of the relative merits of each waste management method, providing valuable insights for stakeholders and policymakers in formulating sustainable strategies for broiler waste management.

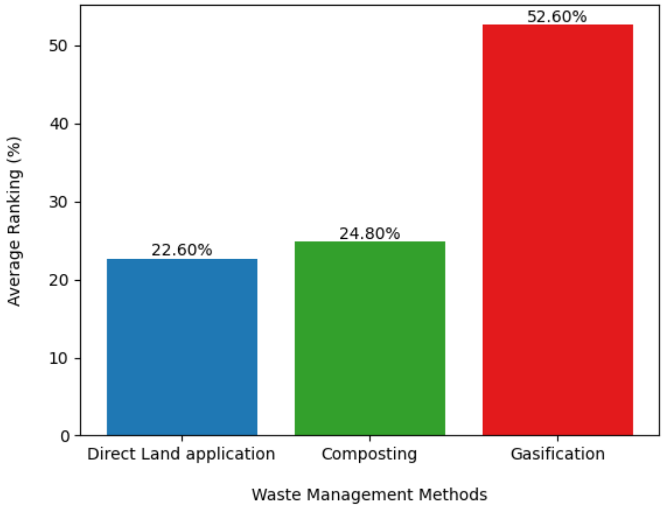

Fig. 3. Average ranking of broiler waste management methods.

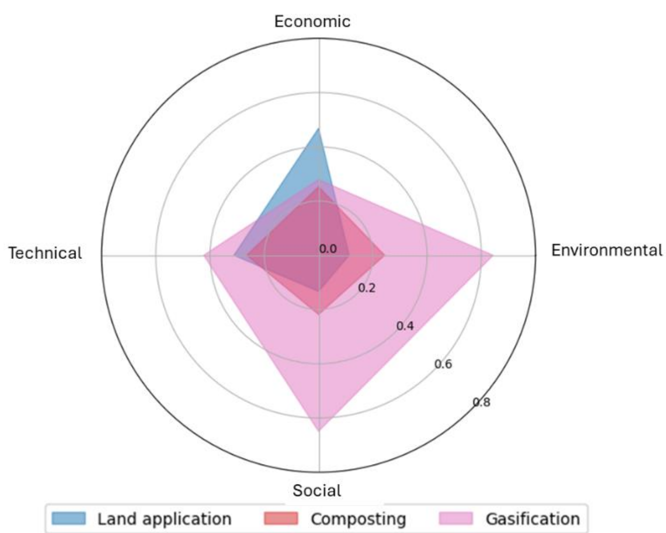

Fig. 4. Broiler waste management: multi-criteria performance chart.

V. CONCLUSION

In addressing the critical need for sustainable broiler waste management in Thailand, a prominent global producer and exporter of broiler meat, this study conducted a comprehensive assessment of three waste management methodologies: direct land application, composting, and gasification. Employing an Analytic Hierarchy Process (AHP) analysis, the research meticulously examined environmental, economic, technical, and social criteria, encompassing a total of 15 sub-criteria. Notably, climate change emerged as the highest priority sub-criterion (0.2272), closely followed by water use (0.1324).

The study identifies gasification as the optimal choice, commanding a preference rate of 52.6%, followed by composting at 24.8%, and direct land application at 22.6%. A nuanced analysis underscores gasification's outstanding performance in environmental and social aspects, while direct land application proves economically effective. Furthermore, composting demonstrates a well-balanced performance across all four criteria.

This research innovatively introduces an AHP model into the domain of broiler waste management, providing policymakers with invaluable insights for formulating sustainable, long-term strategies. The findings contribute to the discourse on effective waste management practices, offering a robust foundation for evidence-based decision-making in the agricultural sector. The nuanced evaluation of waste management methodologies presented in this study enhances our understanding of the intricate interplay between diverse criteria, thereby facilitating the development of informed and sustainable policies for broiler waste management.

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