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Discussion of the economic benefits of biogas slurry irrigation by analytic hierarchy process (AHP)

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Abstract

In this study, the benefits of Biogas slurry irrigation on farmland were evaluated in the background of circular economy. Biogas slurry irrigation is a worldwide option to promote sustainable agriculture and the policy of biogas slurry irrigation has been implemented nationally for more than five years in Taiwan. As the result, the number of irrigating households has been increasing year by year. In this study, we implemented a questionnaire to apply a two-by-two comparison question to the same group of respondents and used the analytic hierarchy process (AHP) to evaluate the factors including cost of fertilizer, environmental benefits, food safety benefits and operational costs in order to analyze the benefits of irrigation. Accordingly, the evaluation results show that 31% in fertilizer cost, 26%

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in environmental benefits, 23% in food safety benefits and 20% in operating costs conform to pairwise comparison matrix consistency results after validation that the fertilizer cost which has the highest percentage is the most important issue for farmers. Facing the global climate change and rising raw material prices, farmers will have to pay higher costs for fertilizers in the coming future. Therefore, Biogas slurry substitution is proven to not only solve the problems of chemical fertilizers in environmental damages but also creating a sustainable business model to achieve the circular economy policy encouraged by the government in accordance with the global trend of environmental protection.

Subject Classification: *91B76.*

Keywords: *Biogas, Circular economy, Analytic hierarchy process (AHP).*

1. Introduction

Environmental pollution is a serious problem for livestock industry. In the early days, the main sources of pollution came from river and air which were disgusted by most people in the country. However, the climate change has become the major disaster around the world in the recent years. Emissions of methane are 27.9 times higher than those of carbon atoms has a substantial contribution in mitigating the climate change. 105 countries from the United Nations Climate Change Conference (COP26) where jointly signed the Global Methane Commitment (GMC) have declared a 30% reduction in emissions of methane by 2030.

Agriculture and livestock industry must respond to climate change and the challenges rose from circular economy due to growing global population. Therefore, Biogas slurry irrigation in agriculture is regarded as one of successful examples to solve the problem. It is approved that the manure and urine wastewater discharged from animal husbandry still retains nitrogen, phosphorus, potassium and various trace elements (Lin, 2018). As an alternative to chemical fertilizers, the integration between livestock and agriculture can help reduce wastes and promote sustainable development in circular economy.

Biogas slurry irrigation has been implementing for around five years in Taiwan, during the period governments and livestock farmers together have been working and implementing various projects through the cooperation between industry, government and academy. Accordingly, many issues were encountered during the implementation including increased number in irrigating farmers, farmers' education on biogas slurry is not enough and how to build a business model of circular sustainability. For instance, pig wastewater is treated by separating solid from liquid and anaerobic fermentation for more than 10 days to meet the chemical oxygen demand (COD) of 600 ppm or less (shown in Figure 1) in order to be released and recycled (Institute of Animal Products, Council of Agriculture, Executive Yuan, 2010). At present, we promote the reclaim of wastes of livestock as the supply materials for biogas slurry irrigation and using tankers to carry biogas slurry to the fix points for watering. In addition to the nutrients required by crops such as nitrogen, phosphorus and potassium, biogas slurry is rich in organic matter, humus acid, calcium, copper and iron (Song et al., 2016). It is to say that a long-term irrigation of biogas slurry is the main demand of farmers and can improve soil acidification and reduce fertilizer costs. The use of biogas slurry, biogas residue and biogas can all be regarded as resource recycling and as an innovative approach to resource utilization.

New technologies are being developed around the world in an effort to reduce cost and risk in agriculture. The nitrogen generated from biogas slurry is between 300 and 600 ppm depending on the number of days in fermentation and other conditions. It is therefore to say that biogas slurry is a liquid fertilizer that can be absorbed quickly into the field within a short time and does not produce odor to the air that provides the same value of elements as artificial fertilizers. Also it can reduce carbon and has the ability to improve the soil matrix (Sandeep, 2015). The biogas slurry used in this study was mainly from the Central Livestock Co., Ltd. and the content of nitrogen was about 516 mg/kg per unit of biogas slurry. Within 7 tons of biogas slurry, it was converted to about 3.6 kg nitrogen which is equivalent to 3 packets of 20 kg organic fertilizer. organic fertilizer nitrogen contained about 0.05%~1% nitrogen accounted around 1 kg~2 kg of nitrogen per packet (Chen et al., 2010) and proving the effectiveness of biogas substitution.

Another risk of biogas slurry irrigation is heavy metal contamination. Copper and zinc are often added to livestock feeds which are metabolized by animals and resulting in high concentrations of copper and zinc in manure and urine (Guo, 2010). The ability of crops to absorb copper and zinc is limited so it is speculated that the concentration of copper and zinc in the soil will be gradually accumulated. In order to prevent diseases and promote growth in the process of raising pigs, heavy metals such as copper and zinc play an important role in helping protein synthesis, metabolism and immune system especially during the growth period (Institute of Livestock Research, 2019). The feed contains copper and zinc where about 30% of which is absorbed by the body of pigs and the rest is excreted in the feces. Using rice as an example, the zinc content of Taiwanese rice is 15.53

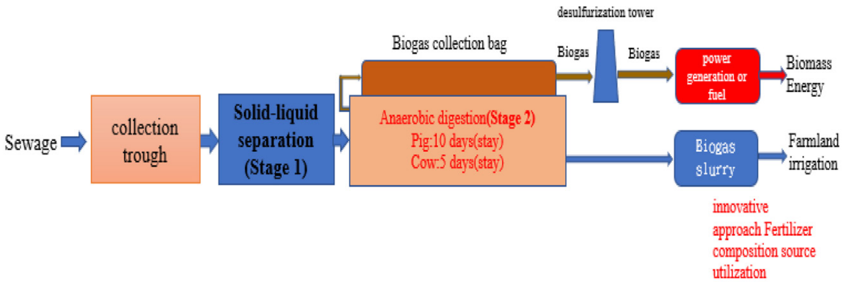

Figure 1

Three-stage wastewater treatment method and anaerobic fermentation 10-day fertilizer resource flow chart

ppm compared with Japanese rice is 16.20~23.41ppm is still within the required standard level (Lin, 1996). It is to say that Specific mineral elements can maintain the health of the body and provide the energy needed for activity (Lai, 2010).

In this study, for example, the heavy metals of the biogas slurry did not significantly exceed the standard required. In view of the implement of the current biogas slurry program, it is important to explore the barriers to its implementation. In comparison the differences of the current policy of biogas slurry irrigation in Taiwan and abroad, we induced on cost effectiveness, environmental benefits, food safety benefits and the strategies of industry through the cooperation between industry, government and academy according to fee subsidy program and user-pays policy. Since the current resource utilization ratio of livestock farmers is limited to 10%, livestock farmers and farmers must jointly operate the business of methane in order to increase the resource utilization ratio and achieve the concept of sustainable management. This study examines and analyzes the influences between the cost of fertilizer, environmental benefits, nutritional benefits and operational benefits as a reference for implementation in policy of biogas irrigation and will be able to establish a circular sustainable agriculture in the future.

2. Literature Research

2.1 *Research on Biogas slurry irrigation Policy and Circular Economy*

According to the data from the Livestock Division of the Council of Agriculture of Taiwan during 2021 to 2022, the biogas slurry irrigation application volume has been growing by 5% and the total biogas slurry irrigation areas are increased to 18%, the fertilizer has been saved by 5% and the carbon reduction effect is therefore achieved. It can be seen that the biogas slurry irrigation program is being gradually promoted and improved (Institute of Animal Products, Council of Agriculture, Executive Yuan, 2022). Although the traditional three-stage treatment method can remove up to 95% of organic pollutants, the waste water from livestock farms is not properly treated due to high electricity costs in this complex treatment procedures and will be discharged directly into rivers in causing pollution (Institute of Nuclear Energy, Atomic Energy Commission, Executive Yuan, 2020).

Although agricultural waste resourcing is an international trend, the linear economy and the environment are bound to be difficult to work combine. In the face of future environmental challenges, the circular economy is focusing on "the reduction, reuse, and resourcing in the processes of production, distribution, and consumption" (Industrial Research Institute, 2017). River pollution is often a major concern for food safety and health. In Taiwan, there is no clear separation between factories and rice fields and pollution incidents are common. Although the biogas slurry of livestock waste often contains relatively low heavy metals, a long time accumulation in the environment will cause environmental hormonal effects. It is therefore to say that the direction of sustainable agriculture should effectively apply the energy of resource utilization to avoid the impact on food safety due to environmental factors (Agricultural Technology Monthly, 2019).

At present, Taiwan's livestock industry is gradually becoming a large enterprise and the overall investment in environmental protection and resource recovery equipment is more abundant. The livestock industry that raises less than 1,000 pigs is currently focusing on the planning of a pooled biogas center (Wei, 2022) and moving toward a resource-based and energy-based circular economy business model (Environmental Protection Agency, Executive Yuan, 2019).

Since biogas slurry is liquid with a large volume, the distance is therefore a crucial consideration where over 10 kilometers between fields and livestock farmers can effectively increase the cost of biogas slurry irrigation. The initial phase of the plan is for counties and cities to purchase their own tankers for irrigation. The lowest cost is within 3 km to 5 km of the planned irrigating area. If the distance exceeds the set number of kilometers, the irrigating and transportation efficiency will be poor and the cost will be increased. In the face of the increasing number of biogas slurry irrigation farmers, it is inevitable to adopt a subsidized program in tanker trucks and bucket tanks for livestock farmers. It is clear that transportation costs are the focus of the project (EPA Biogas Digestate Irrigation Preliminary Preparation and Operational Effectiveness Evaluation Project, 2018). The cost and subsidy measures have been the indicators for the continuation of the biogas slurry irrigation policy. In view of this, the user pays policy can be operated in the long term accordingly where the plan farmers need to pay each tanker at the cost of about $ 5 fee and the rest of the cost is paid by the livestock farmer. The cost is therefore based upon a long-term operational strategy. This study conducted a questionnaire survey on the cost issue referring to the farmers' opinions on the user fees when the subsidy policy is stopped in the future and to facilitate the continuous promotion of the biogas slurry irrigation program in order to overcome the problem of biogas slurry transportation cost. It will allow the location of biogas slurry fertilizer distribution becoming more flexible so as to facilitate more farmers in the biogas slurry fertilizer distribution program and reduce the pollution caused by the discharge of livestock wastewater into rivers.

2.2 *Decision Analysis Applied to biogas slurry irrigation Planning*

For agricultural system implementation policies, a hierarchical analysis method is used to deal with complex problems and is to establish the interrelationship between options at each level by decomposing the problems and this determines the best evaluation benefits by the attributes of experts and groups on current agricultural policy analysis (Chang, 2016). The hierarchical analysis method uses a pairwise comparison of two attributes as the data for question judgment. The pairwise comparison is relatively simple and easy to understand, which helps the evaluator to think and be able to focus on the comparison between attributes. As the result, the consistency is checked for the main components by weighting indicators to establish a reasonable hierarchy (Ho, 2018). Exploring the policy in response to management structure including capital planning and management capability analysis and thus reduces wrong policies application from costing unnecessary money and time (Wu, 2016).

2.3 *Application of Analytic Hierarchy Process (AHP)*

Analytic Hierarchy Process (AHP) developed by American professor Thomas L. Saaty in 1971 is widely used in evaluation and decision making statistics to analyze decisions under uncertainty and multiple evaluation criteria. The inspection data should pass the consistency check and the hierarchical consistency check to calculate the value and project the best solution (Huang, 2016).

3. Research Methods

3.1 *Research process and steps*

The first step of this research process is to determine the researcher's attributes and the research topic. The second step is to interview the personnel involved and design the questionnaire according to the collected opinions. The third step is to distribute and collect the questionnaire. The fourth step is to calculate and rank the collected questionnaire data by hierarchical analysis. The fifth step is to compare and discuss the analysis results.

3.2 *Establishment of evaluation framework*

Biogas slurry irrigating benefit is the first level. The second level is based on cost effectiveness, environmental benefit, food safety benefit and operation cost. The third level is the sub-structure as shown in Figure 2, by designing a paper questionnaire to biogas irrigating related personnel includes four irrigating farmers, two livestock farmers, one project-related staff, one school teacher and one project facilitator from government-related units, all of whom had 3 years of relevant work and experience in methane irrigating and the weight of each unit was calculated and ranked.

3.3 *Evaluation Criteria*

Cost-effectiveness: The cost of fertilizer has always been the largest cost of agricultural expenses according to the survey of farmers' expenses and the option of transport costs for operators. Biogas slurry is alternative fertilizers that can help farmers save on fertilizer expenses where the cost of transporting biogas slurry irrigating is currently subsidized under the governmental program. The evaluation of the benefits in cost effectiveness after the future business transition is an important assessment.

Environmental benefits: Biogas irrigating is an important part of the agricultural circular economy which can improve soil acidification and reduce the use of chemical fertilizers. The long-term irrigating of biogas slurry has a decomposing effect on soil humus and is a method of natural cycle fertilization.

Food safety benefits: The biggest risk of biogas slurry irrigation is the heavy metals including copper and zinc. However, the content of heavy

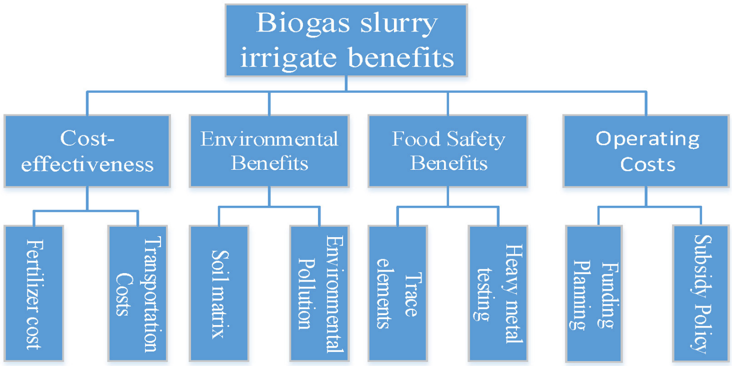

Figure 2

Hierarchical analysis framework of biogas slurry irrigation benefit assessment

metals in biogas slurry is relatively low. Due to the effect of solid-liquid separation at the initial stage, the rice watered by biogas slurry has a certain content of trace elements and dietary fiber. As the result, biogas slurry has an alternative effect on chemical fertilizers.

Operating cost: Since the implementation of the biogas policy in 2017, the subsidy policy and plan must be evaluated towards the possibility of future business transition. With the tripartite opinion from industry, government and academy in this questionnaire survey, it is expected that through the evaluation of operating cost the future biogas irrigating can be developed sustainably.

4. Research Results

4.1 *Compilation of subject data*

The total number of respondents in this study was 9, 9 questionnaires were collected, 9 valid questionnaires were returned, 100% of the respondents were male and 0% were female. Biogas slurry irrigation is a specialized industry, so this questionnaire was administered to respondents of this attribute. In terms of gender, they are mainly male and have more than 3 years of experience in biogas watering.

4.2 *Analytic Hierarchy Process (AHP) calculation and analysis of results*

(1) In this study, the geometric mean of each group was compared by two-comparison questionnaires to calculate the weight and ranking in order to establish a pairwise comparison matrix. From

the returned valid questionnaires, two-comparisons were obtained, e.g., there were 9 respondents in the pairwise comparison of cost effectiveness and environmental benefits, the results of the pairwise comparison were obtained by first multiplying the values given by each respondent and then open the square root to the 9th power to have the results of the pairwise comparison 1.38. After the results of the two-comparison geometry calculation for each item, it was then used to establish a pairwise comparison matrix, as shown in Table 1.

(2) Calculation of eigenvalues and eigenvectors (weights): The weights are calculated by applying the pairwise comparison matrix to the geometric average of the column vectors, as shown in Table. First multiply the values in Table 1 and then then open the square root to the 4th power (because there are 4 factors in the level 2 evaluation) to obtain values which are 1.26, 1.05, 0.92, and 0.82 and has a total of 4.01. Then, the values of 1.26, 1.05, 0.92 and 0.82 were divided by 4.01 to obtain the weights (W) of each factor, which were 0.31, 0.26, 0.23, and 0.20, respectively.

(3) Calculation of the maximum eigenvalue: After obtaining the weight (W) in Step 2, the weight of the maximum eigenvalue item is then calculated to obtain the normalized matrix in Table 2. Then, the column sum of the normalized matrix Q (Table 3) is calculated, the new eigenvector W1 is obtained by dividing the column sum of each item (Q) by the weight (W) and finally (λ max) is calculated. The maximum eigenvalue (λ max) is obtained by multiplying each value of the matrix in Table 3 by the sum of W1 and dividing by 5 (the number of factors of the evaluation criteria).

(4) Consistency check: The pairwise comparison matrix values are subjectively scored by the test subjects. However, because there are too many judgment levels and factors, there may be inconsistencies in the judgment criteria given by the test subjects after two comparisons. Therefore, in order to confirm the consistency of the decision makers when making pairwise comparisons, a consistency check must be performed.

The consistency index (C.I.) and the consistency ratio (C.R.) are calculated to check whether the pairwise comparison matrix formed by the answers given by the decision makers is a consistency matrix. According to Saaty's suggestion, the best acceptable error is when C.I < 0.1; If C.R. < 0.1, then the consistency of the matrix is satisfactory, meaning that the characteristic value, n, is the number of factors in the evaluation criteria, i.e., λ max minus n (5.06 - 5) divided by n minus 1 (5 - 1) yields a C.I. value of 0.02, which is within the 0.1 error suggested by Saaty, indicating the consistency of the pairwise matrices. This means that the paired scale has a certain degree of "reliability".

Table 1

Pairs of comparison matrices & Weight calculation

	Cost-effectiveness	**Environmental Benefits**	**Food Safety Benefits**	**Operating Costs**
Cost - effectiveness	1	1.38	1.32	1.38
Environmental Benefits	0.72	1	1.36	1.26
Food Safety Benefits	0.76	0.74	1	1.26
Operating Costs	0.72	0.79	0.79	1

Table 2

Calculation of normalized matrix

	Cost-effectiveness	**Environmental Benefits**	**Food Safety Benefits**	**Operating Costs**
Cost - effectiveness	1*0.31	1.38*0.26	1.32*0.23	1.38*0.20
Environmental Benefits	0.72*0.31	1*0.26	1.36*0.23	1.26*0.20
Food Safety Benefits	0.76*0.31	0.74*0.26	1*0.23	1.26*0.20
Operating Costs	0.72*0.31	0.79*0.26	0.79*0.23	1*0.20

Table 3

Eigenvalue of maximum Calculation

	Cost-effective-ness	**Environ-mental Benefits**	**Food Safety Benefits**	**Oper-ating Costs**	**Total col-umn**	**(Weight-ing)**	**(W1)**
Cost - effectiveness	0.31	0.36	0.3	0.28	1.26	0.31	1.26/0.31 = 4.06

Contd...

Environmental Benefits	0.22	0.26	0.31	0.25	1.04	0.26	1.04/0.26 = 4
Food Safety Benefits	0.24	0.19	0.23	0.25	0.91	0.23	0.91/0.23 = 3.97
Operating Costs	0.22	0.2	0.18	0.2	0.8	0.2	0.8/0.20 = 4
						(λ max)	16.03/4 = 4.01

(5) consistency index C. I.

$$C.I. = \frac{\lambda \max - n}{n-1}$$

4.01-4/4-1=0.03 (conform to consistency index C. I.)

(6) Consistency ratio, C.R

$$C.R. = \frac{C.I.}{C.R.}$$

Saaty proposed the so-called Randomized Indicator (R.I.) to adjust the consistency ratio for different degree (C.I.) value changes. After checking the RI experimental data table, the 4th order R.I. value is 0.9

0.03/0.9=0.03(conform to Consistency ratio, C.R.)

5. Conclusion

In this study, we obtained the criteria for evaluating the implementation of biogas slurry irrigation through literature analysis and questionnaire. The overall weighting of farmers' opinions on the cost of fertilizer is 30% compared to the other three items. The opinion on environmental benefits is ranked 2nd and clearly indicates that sustainable environment is the common idea between farmers. The results show that those who participated in the biogas slurry project have environmental awareness and are willing to continue to implement it. The food safety benefits and the environmental benefits have the similar weights where farmers are especially expressed the certain degree of importance in this assessment. The operating cost is the lowest weight for this assessment. However, the result of all assessment items is averaged which indicates a good feedback on these attributes in the questionnaire. After the hierarchical analysis method assessment which shows consistency and indicates this assessment is obviously efficient. In order to effectively assess the fourth item of operating costs in the face of the termination of the future subsidy policy, it is necessary for the livestock industry and farmers to cooperate. The survey showed a consensus between livestock farmers and farmers on this issue which will be of great benefit to sustainable development.

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