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Resource utilization technology of fishery waste based on the concept of circular economy

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SUMMARY: *This paper applies the concept of a circular economy to the fisheries sector to achieve sustainable and green development in fisheries. Through the use of physical, chemical, and biological technologies, fisheries waste is recycled and utilized as a resource. This study takes the anaerobic gas production method for fisheries waste as an example to explore the optimal fermentation gas production scheme for fisheries waste, comprehensively comparing the gas production effects of different mixing schemes between fisheries waste and various solid wastes. After applying the resource utilization technology for fishery waste described in this paper, an economic analysis is conducted to calculate the construction costs and benefits of the project, thereby verifying the economic viability of the resource utilization technology for fishery waste. The daily gas production process of anaerobic fermentation using a mixture of fishery waste, kitchen waste, and activated sludge is the most stable, with a total gas production of 31,159 mL over 40 days, significantly higher than other schemes. The cumulative present value of costs, cumulative present value of benefits, and cumulative net present value of benefits for the fishery waste resource utilization project are 7,568,000, 11,807,500, and 4,239,500 yuan, respectively. The internal rate of return is >0.1, the benefit-cost ratio is >1, the dynamic payback period is 2.50 years, the net present value after three years of operation is >0, and the net present value ratio is >0, indicating good economic benefits.*

KEYWORDS: *circular economy; waste resource utilization; anaerobic gas production; economic benefits*

1 Introduction

In 2022, the global total production of fisheries and aquaculture reached 223 million tons, an increase of 4.4% compared to 2020, with the added value continuing to expand, and the influence of fisheries on agricultural economic development becoming increasingly significant. However, while achieving these accomplishments, the development of fisheries production also faces numerous challenges. Traditional fisheries production methods suffer from severe inefficiencies in resource utilization. For instance, 1 ton of water used to produce wheat yields a value of 0.3 USD, while the same amount used for industrial production yields 14 USD, but when used for traditional fish farming, it yields only 0.07 USD [1, 2]. On the one hand, environmental pollution, engineering projects, and natural disasters have damaged fish spawning grounds, feeding grounds, and migration routes, leading to sharp contradictions between resource environments and fisheries production [3, 4]. On the other hand, waste generated during fishery production, including fishing vessel waste, fishing net waste, fishing

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gear waste, and fishery processing waste, causes certain pollution and harm to the environment [5, 6]. Additionally, in the current context of globalization, competition among countries for the development of high seas resources has intensified, further exacerbating the rigid constraints on fisheries production activities [7]. According to the report in [8], in a single fishing operation, inorganic and organic waste accounted for 55.56% and 44.44% of total waste, respectively, indicating that the reuse of fisheries waste is urgently needed.

The traditional "extract-manufacture-use-dispose" linear economic development model is characterized by high pollution, high energy consumption, and low output. The approach of "pollute first, then treat" has been proven unsustainable in practice [9, 10]. In the new wave of international factor mobility, innovation-driven development, and industrial restructuring, how to seize the opportunities of economic transformation, find the right direction, and achieve sustainable development is a topic worthy of research [11]. As a fishery production system based on circular economy theory, circular fisheries adhere to the 3R principles of "reduce, reuse, recycle," minimizing resource and material inputs during production, enhancing resource reuse rates, reducing waste emissions, and achieving harmonious development between fisheries and ecology [12-15]. The production process of circular fisheries is a feedback-based closed-loop circular economy process, manifested as a circular feedback-based economic model composed of "fisheries resources—products—regenerated resources," characterized by "low pollution, low energy consumption, and high output" [16-18]. It is evident that the rational utilization and treatment of fisheries waste can also serve as a means of resource reuse. However, the resource utilization of fisheries waste cannot be achieved without technological support.

In the current fisheries industry, literature [19] describes the use of biotechnology and processing technology to convert fish processing waste into high-value products such as collagen, gelatin, and enzymes, optimizing traditional methods like high-temperature drying and fermentation to produce fish meal, animal feed, and fertilizers. Literature [20] employs nanobiotechnology to convert seafood waste into carbon nanomaterials, which are then applied to remove and detect pollutants in food. Literature [21] summarizes that through technical means such as screening, purification, and energy production, biological refining is achieved during the fisheries production process, enabling the reuse of waste. Literature [22] reports that microwave hydrothermal carbonization technology and conventional hydrothermal carbonization technology can convert fish waste into water carbon, which possesses strong adsorption capacity, thereby contributing to environmental protection and ecological sustainability. Literature [23] applies microbial fermentation technology to hydrolyze flounder waste using Aspergillus oryzae, and also performs antioxidant conversion of Atlantic mackerel skin using Aspergillus oryzae, thereby achieving high-value conversion and environmental protection of waste. Literature [24] mentions that algal biotechnology converts nutrients in seafood waste into other new value components and raw materials through single-cell protein conversion, while combining biorefining methods for environmental management of waste. Literature [25] processes fish waste using green technology and seaweed bioplastic packaging technology, and combines blockchain technology for traceability and transparency, thereby reducing carbon emissions and pollution. With the development of smart technology, various emerging technologies have been applied to the utilization of fishery waste. Literature [26] mentions that to achieve a blue economy and sustainable food development, artificial intelligence, big data, sensors, and other technologies are used to process and utilize fishery waste. However, most of these technologies focus on waste treatment, and further development is needed in terms of utilization. Therefore, in the context of increasing volumes of fishery waste, it is of significant importance to continuously develop resource utilization technologies for fishery waste from a circular economy perspective.

To promote green development in the fisheries production sector, this paper proposes resource utilization technologies for fisheries waste based on the principles of the circular economy. These technologies involve the resource-based processing of fisheries waste through physical, chemical, and biological methods. Taking algae as an example, they can be subjected to anaerobic digestion, material extraction, feed production, and aerobic composting to enhance the utilization of algae resources in fisheries.

2 Resource utilization of fishery waste based on the circular economy

2.1 Circular Economy

A circular economy [27] is essentially an eco-friendly economy that requires the application of ecological principles to guide human economic activities. Compared with the traditional economy, the difference lies in the fact that the traditional economy is a linear economy characterized by a one-way flow of “resources-products-pollution emissions,” with high extraction, low utilization, and high emissions. In the traditional economy, people intensively extract materials and energy from the Earth, then release large amounts of pollution and waste into water, air, and soil. Resource utilization is extensive and one-time, achieving quantitative economic growth by continuously transforming resources into waste. The circular economy, in contrast to the traditional economy, advocates an economic development model that harmonizes with the environment, requiring economic activities to form a feedback-based flow process of “resources-products-recycled resources.” All materials and energy must be utilized reasonably and sustainably within this ongoing economic cycle, thereby minimizing the impact of economic activities on the natural environment. The circular economy provides a relatively balanced strategic theoretical framework for transitioning from the traditional economy since industrialization to a sustainable economy, fundamentally resolving the long-standing contradiction between environmental protection and development.

The circular economy is an economic growth model centered on the efficient and circular use of resources, guided by the principles of “rethink, reduce, reuse, recycle, and repair,” characterized by low consumption, low emissions, and high efficiency, and aligned with the concept of sustainable development. It represents a fundamental transformation from the traditional growth model of “mass production, mass consumption, and mass disposal.”

The circular economy integrates clean production and the comprehensive utilization of waste resources into a single economic system. It requires the application of ecological principles to guide human economic activities. By restructuring the economic system according to the material cycle and energy flow laws of natural ecosystems, the economic system is harmoniously integrated into the material cycle of natural ecosystems, thereby establishing a new form of economy. The circular economy requires organizing economic activities into a feedback loop of “natural resources-products and goods-recycled resources,” ensuring that all raw materials and energy are utilized in the most reasonable manner within this continuous economic cycle, thereby minimizing the impact of economic activities on the natural environment. The two-way flow process of “resources-products-recycled resources” constitutes the model of the circular economy.

The circular economy is a combination of ecological economic principles and knowledge economy laws, based on the carrying capacity of ecosystems, featuring efficient economic processes and a networked, evolutionary economy with integrated, synergistic, circular, and self-sustaining functions. It integrates production, circulation, consumption, recycling, environmental protection, and capacity building through vertical, horizontal, and regional integration, enabling the multi-level utilization and efficient elimination of materials and energy, the positive accumulation and sustainable use of natural assets and ecological services, and the transformation of pollution-related negative benefits into economic positive benefits. The diversity and advantages, openness and autonomy, intensity and flexibility, speed and stability of circular economy development achieve an organic integration, promoting the transformation of traditional resource-exploitative and environmentally depleting product-based economies into emerging circular economies. This requires the promotion of spatio-temporal restructuring based on ecological theory. The current circular economy primarily draws its theoretical foundation from human ecology, composite ecology, and industrial ecology principles.

2.2 Classification of technologies for the resource utilization of fishery waste

2.2.1 Physical treatment technology

Using physical methods, solid and liquid components in fishery waste can be separated, thereby reducing its volume and moisture content while concentrating nutrients, laying the foundation for subsequent resource recovery. Common physical treatment technologies include sedimentation, filtration, centrifugal separation, mechanical pressing and dewatering, evaporation, and drying. These technologies are favored for their ease of operation, low cost, and scalability for large-scale applications. However, the waste remaining after physical treatment still contains a significant amount of organic components, which require further processing to achieve resource recycling.

2.2.2 Chemical treatment technology

Using chemical treatment technology, harmful substances in fishery waste are converted into environmentally harmless or beneficial substances through specific reactions. This approach reduces environmental threats while enhancing the efficiency of nutrient recovery. Common chemical methods include acid addition, alkali addition, oxidation, reduction reactions, hydrolysis, and fermentation processes. These technologies are highly effective in accelerating treatment rates and eliminating pathogens, but their processing may generate harmful byproducts that could cause secondary environmental pollution.

2.2.3 Biological treatment technology

Biological treatment technology utilizes the metabolic activities of microorganisms such as bacteria to convert the organic components in fishery waste into inorganic forms, thereby reducing organic matter content and enhancing the concentration of nutrients. Common forms of this technology include anaerobic fermentation, aerobic decomposition, biological composting, and composting using earthworms. The advantages of microbial degradation methods include high treatment efficiency, no secondary pollution, and low cost. However, their disadvantages include a relatively long treatment cycle and high requirements for surrounding environmental conditions.

2.3 Algae Resource Utilization Technology

Algal blooms are one of the most common water quality hazards to date, reducing drinking water quality and having harmful effects on human physiology and psychology; lowering dissolved oxygen concentrations in water, threatening the survival of aquatic plants and animals; and emitting greenhouse gases. Algae are rich in nitrogen, phosphorus, and various organic compounds, and if effectively utilized, they hold great potential for resource recovery. Currently, the main technologies for algae resource recovery include anaerobic digestion technology for recovering biomass energy, extracting useful substances from algae for research and the cosmetics industry, utilizing algae's high protein content directly as feed, and aerobic composting of algae to produce fertilizer while achieving harmless treatment. Algae resource recovery technologies are illustrated in Figure 1.

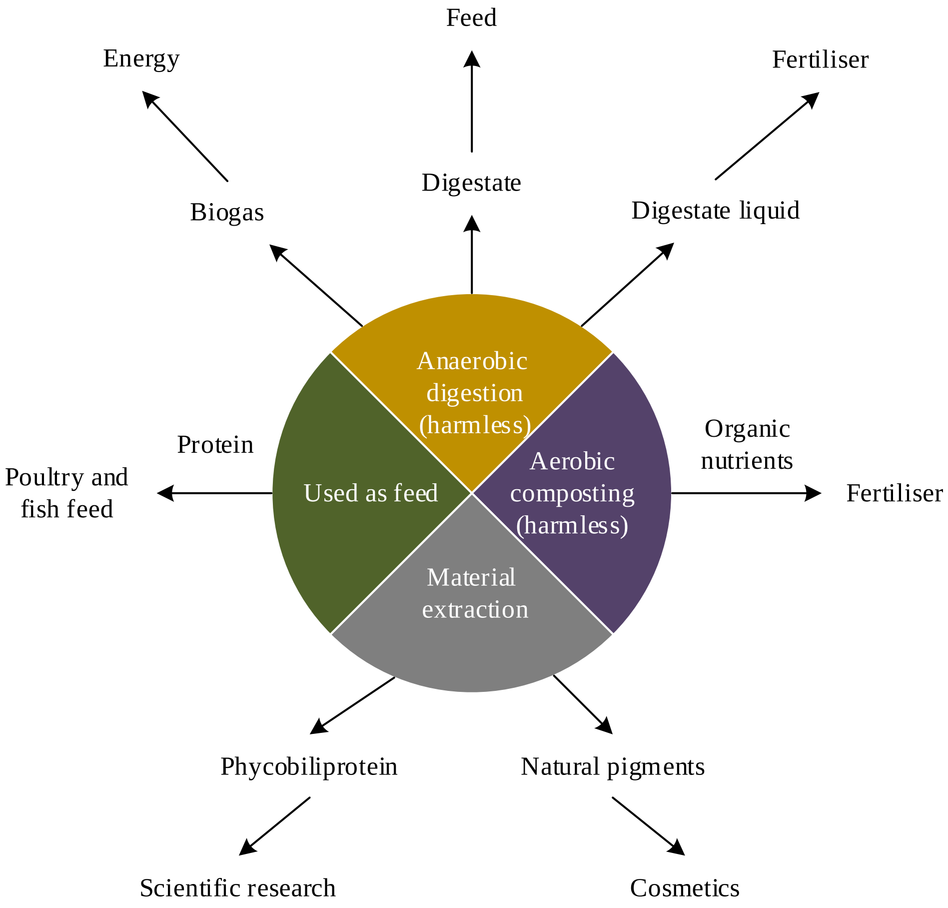

Figure 1: Schematic diagram of resource utilization technologies for algae

2.3.1 Anaerobic digestion

Anaerobic digestion of algae is a green, energy-efficient, and economical treatment method that not only reduces the accumulation of blue-green algae but also recovers biogas (biomass energy). Algal-based biorefinery platforms play a crucial role in the closed-loop circular economy of anaerobic digestion. In addition to using the entire biomass of microalgae and macroalgae as feedstock for biogas production, the integration of anaerobic digestion with other biological or thermochemical conversion technologies can achieve complete stabilization of biomass residues after processing or extraction of valuable compounds. Furthermore, algae and their consortia with bacteria or fungi can be utilized for combined biogas upgrading and wastewater treatment. The methane production potential of algae was studied through anaerobic digestion with the addition of peroxymonosulfate (PMS), and the removal of microcystins was analyzed and discussed. It was found that anaerobic digestion recovers energy from algal sources in the form of methane gas, unaffected by the presence of microcystins, with a removal rate exceeding 99%; simultaneously, anaerobic digestion reduced the total content of Cd and Zn in the liquid phase while increasing the total content of Cr and Pb in the liquid phase. This study provides new insights into microbial mechanisms, microcystin detoxification, and the migration patterns of heavy metals in algal biomass during biogas production.

2.3.2 Material extraction

Algae are one of the most primitive and simplest single-celled organisms, thriving in diverse environments and rich in various nutrients and bioactive compounds. Additionally, algae are a renewable resource with an abundant supply. Therefore, the extraction of biological resources from algae (such as Microcystis, Anabaena, Cyanobacteria, and Mutant Cyanobacteria, among others) has garnered increasing attention. Research has shown that by subjecting Microcystis from Lake Chaohu to repeated freeze-thaw cycles, followed by HA column chromatography and elution, crude extracts of algal proteins (including phycocyanin and phycocyanin) can be obtained. Furthermore, analysis revealed that these algal protein extracts contain tryptophan and tyrosine. Additionally, cyanobacteria contain various natural pigments that pose no harm to human health, and some can effectively absorb ultraviolet rays. Therefore, they can appropriately replace certain chemically synthesized pigments, enabling the application of various pigments extracted from cyanobacteria (such as phycocyanin, carotenoids, and chlorophyll) in the cosmetics and food industries.

2.3.3 Used as feed

Algae are not only rich in nutrients such as protein but also serve as a abundant source of n-3 polyunsaturated fatty acids, B vitamins, carotenoids, and non-starch polysaccharides (such as β-glucan). Therefore, using algae as a feed additive is another important application of algae. Adding just 0.001% spirulina to chicken feed enhances natural killer cell activity and boosts macrophage phagocytic potential. Grass carp, silver carp, and silver crucian carp can all use spirulina as feed for their own growth, and their weight and survival rates are superior to those of the control group. As such, the nutritional components in algae make them an excellent feed additive for both fish and poultry.

2.3.4 Aerobic composting

Aerobic composting is currently a hot topic in algae treatment research, effectively reducing blue-green algae populations and promoting their recycling, thereby eliminating the harmful effects of algae. Aerobic composting offers distinct advantages for the treatment and disposal of algae: it has a larger processing capacity, with a medium-sized composting facility capable of processing approximately 2 million tons of algae annually; the process is simple, energy-efficient, and cost-effective; related technologies, such as microbial strain cultivation, are already well-established; and aerobic composting enhances the comprehensive utilization of nutrients in algae. Aerobic composting can effectively degrade algal toxins and heavy metals, ensuring the safe utilization of algal resources; by adjusting moisture content, the type of conditioners used, adding chemical additives, and inoculating microbial agents, the degradation rates of algal toxins and heavy metals can be significantly improved.

3 Analysis of the resource utilization of fishery waste

3.1 Comparison of anaerobic fermentation methods for producing gas from fishery waste

This paper analyzes anaerobic digestion fermentation gas production as an example of resource utilization technology for fishery waste, exploring the optimal method for anaerobic fermentation gas production. Fishery waste was mixed with other solid organic waste for anaerobic fermentation experiments, with a total of four experimental groups. Group A consisted of 1,500 g of fishery waste and 750 ml of activated sludge. Experiment B consisted of 1,200g of fishery waste, 150g of dried rice straw, and 750ml of activated sludge. Experiment C consisted of 1,200g of fishery waste, 150g of peanut shell powder, and 750ml of activated sludge. Experimental Group D consisted of 1,200 g of fishery waste, 150 g of kitchen waste, and 750 ml of activated sludge. The materials from each group were placed in a 5-liter anaerobic fermentation tank, and the pH was adjusted to 7.0 to promote the initiation of anaerobic fermentation and improve the quality of biogas production. The tank was then quickly sealed and fermented at 35 ± 1°C. The gas production of each group was analyzed.

3.1.1 Comparison of daily gas production

The anaerobic fermentation experiment began on the first day after startup and continued until gas production had largely ceased, totaling 40 days. The volume of gas produced by each group was measured and recorded daily, and analyzed to obtain the daily gas production variation curve shown in Figure 2. As shown in the figure, Experiment Group A exhibited a single peak, with gas production beginning on the first day of fermentation initiation. The gas production volume gradually increased, reaching a peak value of 3,027 mL on the 8th day, and then gradually decreased after the 9th day, ceasing production by the 21st day. Experiment B group showed a similar pattern to Experiment A group, with a single peak, reaching a peak gas production volume of 2,487 mL on day 8. After day 9, gas production gradually decreased and ceased by day 25. Experiment C showed two distinct peaks (one large and one small), both occurring within the first 20 days of fermentation. After initiating anaerobic fermentation, gas production in Experiment C gradually increased, reaching the first peak of 1,718 mL on day 6, followed by a slight decline. However, gas production remained high and relatively stable, with a second, larger peak of 3,740 mL on day 17, after which it gradually decreased, ceasing by day 40. Experiment D showed multiple peaks with significant daily fluctuations in gas production. As shown in Figure 2, there were four distinct peaks: the first at 1,800 mL on day 5, the second at 2,250 mL on day 12, the third at 2,377 mL on day 17, and the fourth at 3,110 mL on day 25. This indicates that the fermentation system in Experiment D exhibited sustained gas production with strong stability in daily gas production processes.

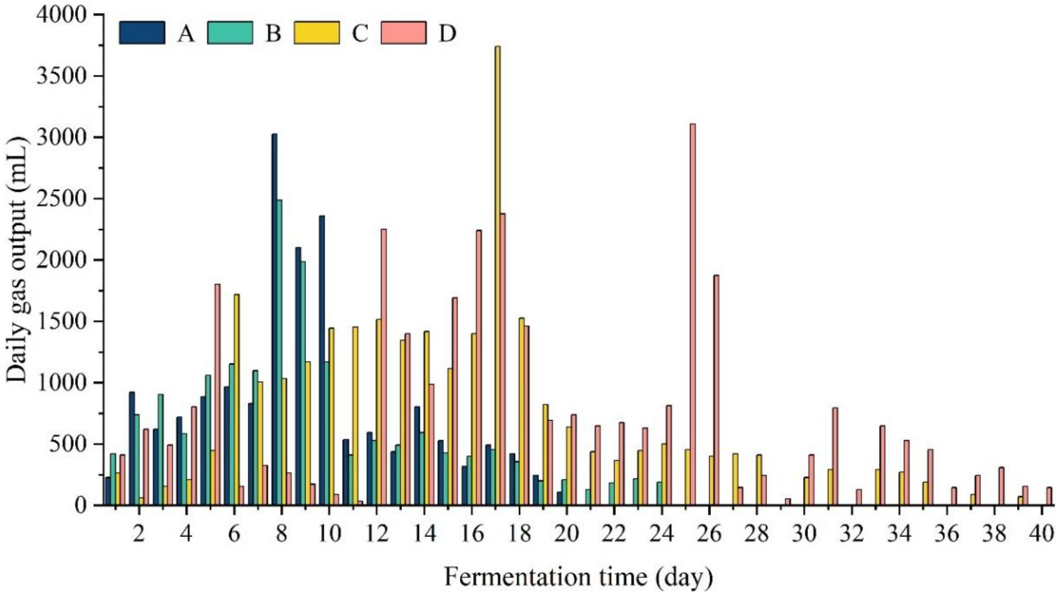

Figure 2: The changes of gas production quantity daily

3.1.2 Comparison of cumulative total gas production

The cumulative total gas production results for each group are shown in Figure 3, and the cumulative gas production for each group every ten days is shown in Table 1. Combining the two, it can be seen that the total gas production of experimental group D was the highest, reaching 31,159 mL, with relatively stable gas production. By the 30th day of fermentation, the cumulative gas production accounted for 88.60% of the total gas production. Next is Group C, with a total gas production of 27,341 mL. The main gas production phase was concentrated in the first 20 days, with the cumulative gas production accounting for 82.20% of the total gas production. Experimental Groups B and A had cumulative total gas production of approximately 16,380 mL and 17,147 mL, respectively, which was significantly lower than that of Groups C and D. Additionally, the anaerobic fermentation period for methane production was shorter. This may be attributed to the C:N ratio of the fermentation raw materials in Groups A and B being unsuitable for sustained anaerobic fermentation.

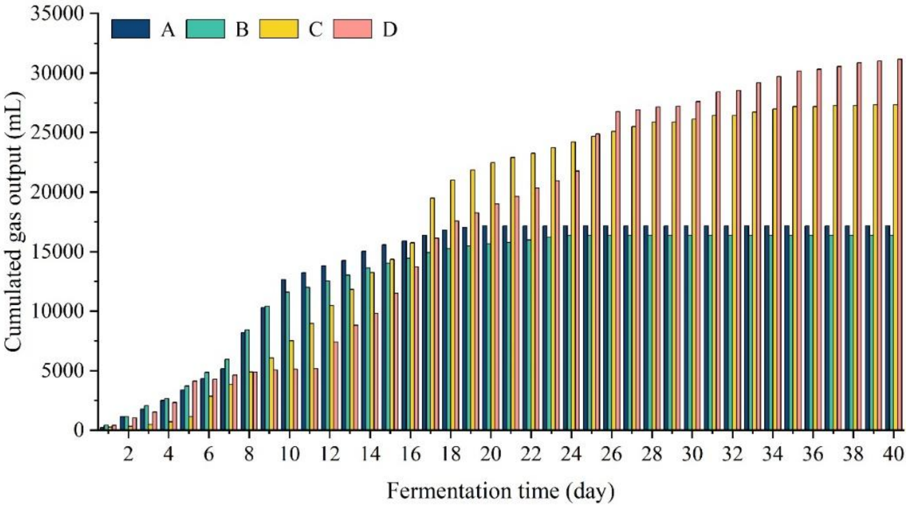

Figure 3: The output changes of accumulating gas

Table 1: Each group’s cumulation gas output every 10 days

Group	Cumulation in 10 days (mL)	Cumulation in 20 days (mL)	Cumulation in 30 days (mL)	Total gas output (mL)	Average methane content (%)
A	12664	17147	17147	17147	64.25
B	11594	15665	16380	16380	72.63
C	7504	22473	26136	27341	73.42
D	5133	19005	27607	31159	75.84

In summary, among the resource utilization methods for producing gas through anaerobic digestion of fishery waste, the method used in Experiment D achieved the best gas production results. Specifically, mixing fishery waste with solid waste such as food waste and activated sludge for mixed fermentation yielded the highest efficiency in gas production.

3.2 Economic Benefit Analysis

3.2.1 Construction Costs

The method in this paper was put into practical application, and the fishery waste was placed and used in three modules: anaerobic digestion and bio-natural gas production, vehicle carrier gas and CO_2 gas fertilizer production, straw filtration and biogas slurry concentration and separation. The process estimation is based on the treatment capacity of the vehicle carrier gas and CO_2 gas fertilizer production module and the small-scale experiment of the straw filtration and biogas slurry concentration and separation module, so the daily processing capacity of fishery waste is 30t, straw is 0.45t, and the annual operation time is 300 days for process estimation.

The cost of putting into production of fishery waste resource utilization technology project is mainly composed of construction cost and operation cost, and the construction content and cost of the whole project are shown in Table 2. The main operating costs in the process of project operation include chemical consumption, raw material costs, electricity costs, oil costs, labor costs, equipment maintenance costs and depreciation costs. Running costs are calculated on a daily basis.

Table 2: Construction costs of fishery waste resource utilization technology projects

Module	Equipment	Unit price/10^4 yuan	Number	Price/10^4 yuan
Anaerobic digestion and bio-gas production module	Cut type sewage pump	0.9	1	0.9
	Centrifugal pump	0.5	2	1.0
	CSTR reactor	5.2	1	5.2
	Desulfurizer	20.5	1	20.5
	Firedamp fan	0.5	2	1.0
	Gas tank	2.2	1	2.2
	Storage tank	2.4	2	4.8
	Control system	1.5	1	1.5
Vehicle gas and CO_2 gas fertilizer production module	CSTR reactor	3.2	1	3.2
	Centrifugal pump	0.5	1	0.5
	Firedamp fan	0.5	2	1.0
	Desulfurizer	20.5	2	41.0
	Absorption tower	24.0	1	24.0
	Regenerative tower	25.8	1	25.8
	Vehicle pneumatic shrinkage machine	10.5	1	10.5
	CO_2 gas fertilizer compressor	8.4	1	8.4
	Vehicle gas tank	0.8	5	4.0
	CO_2 gas tank	0.8	3	2.4
	Control system	5.5	1	5.5
Straw filtration and mass separation module	Centrifugal pump	0.5	5	2.5
	Hammer mill	3.0	1	3.0
	Reeling machine	1.0	1	1.0
	Straw filter	0.6	1	0.6
	Pressure cyclone	0.8	1	0.8
	Inclined plate precision separation device	0.5	1	0.5
	Membrane separation component	0.5	4	2.0
	Storage tank	1.0	4	4.0
	Control system	1.2	1	1.2
Other construction fees	Infrastructure	22.0	1	22.0
	Fire protection equipment	1.8	1	1.8
	Other expenses	2.5	1	2.5
	Public works	2.0	1	2.0
	Various valves		-	12.0
Total	-	-	-	219.3

3.2.2 Economic Analysis

A dynamic evaluation method was used to conduct an economic analysis of this project. The results of the cost and benefit data analysis for the fishery waste resource utilization technology are shown in Table 3 (with a equipment service life of 10 years and a benchmark discount rate of 10%). From the results, it can be seen that the cumulative present value of costs is 7.568 million yuan, the cumulative present value of benefits is 11.8075 million yuan, and the cumulative net present value of benefits is 4.2395 million yuan.

According to the dynamic evaluation method, the internal rate of return (IRR) calculated for this study is IRR = 0.216 > 0.1, the benefit-cost ratio (B/C) is B/C = 1,180.75/756.80 = 1.56 > 1, and the dynamic payback period is: T = 3 - 1 + 39.44 / 78.50 = 2.50. The net present value (NPV) after 3 years of operation is 39.06 > 0, and the net present value rate (NPVR) is 39.06 / (192.32 × 3 - 219.30 - 86.54 × 3) = 0.398 > 0.

Table 3: Cost and benefit analysis table of fishery waste resource utilization technology (104 yuan)

Time /year	Cost	Benefit	Net benefit	Discount factor	Cost present value	Benefit present value	Net benefit present value	Cumulated net benefit present value
0	219.30	0.00	-219.30	1.000	219.30	0.00	-219.30	
1	86.54	192.32	105.78	0.912	78.92	173.56	94.64	-124.66
2	86.54	192.32	105.78	0.835	72.26	157.48	85.22	-39.44
3	86.54	192.32	105.78	0.764	66.12	144.62	78.50	39.06
4	86.54	192.32	105.78	0.691	59.80	131.25	71.45	110.51
5	86.54	192.32	105.78	0.627	54.26	119.74	65.48	175.99
6	86.54	192.32	105.78	0.568	49.15	108.76	59.61	235.60
7	86.54	192.32	105.78	0.521	45.09	98.63	53.54	289.14
8	86.54	192.32	105.78	0.472	40.85	90.42	49.57	338.71
9	86.54	192.32	105.78	0.429	37.13	82.05	44.92	383.63
10	86.54	192.32	105.78	0.392	33.92	74.24	40.32	423.95
Total					756.80	1180.75		

In summary, the technology for recycling fishery waste is feasible and has significant economic benefits.

4 Conclusion

The article is based on the concept of a circular economy and introduces waste resource utilization technology into the fishing industry, aiming to address environmental pollution risks in fishing production and improve the efficiency of waste utilization.

Taking anaerobic fermentation gas production technology as an example in waste resource utilization, through comparison and analysis of several anaerobic gas production methods, it was found that the daily gas production process of mixed anaerobic fermentation of solid wastes such as fishery waste, kitchen waste, and activated sludge is more stable, with the highest total gas production (31,159 mL). In practical applications, the cumulative present value of costs, cumulative present value of benefits, and cumulative present value of net benefits for fishery waste resource utilization projects are 7,568,000, 11,807,500, and 4,239,500 yuan, respectively, demonstrating significant economic benefits.

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