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Production of Wet Organic Waste Ecoenzymes as an Alternative Solution for Environmental Conservation Supporting Sustainable Development Goals (SDGs): A Techno-Economic and Bibliometric Analysis

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ABSTRACT

This study investigates the techno-economic feasibility of producing ecoenzymes from wet organic waste, supported by a bibliometric analysis of relevant global research trends. Spanning a 20-year projection, the study evaluated the production costs, potential profitability, and market pricing of ecoenzymes as an environmentally friendly product. Results indicated that even small-scale, home-based production was economically viable, requiring a minimal daily capital investment of $0.27 (or approximately $80,625 annually). With a selling price of IDR 200,000 per kg, the projected annual revenue was IDR 400,000,000. Notably, the return on investment was achieved within the first three years. The bibliometric analysis highlighted a growing global focus on sustainable waste-to-product conversion. The novelty of this study lied in its application of techno-economic modeling to a previously underexplored product, ecoenzymes from wet organic waste. The findings contribute to multiple Sustainable Development Goals (SDGs), especially SDG 11 (Sustainable Cities), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action).

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1. INTRODUCTION

Waste is defined as discarded materials no longer used by their owners. If not properly managed, waste can threaten environmental sustainability, especially due to its varied decomposition rates in nature (Mutolib *et al*., 2023; Rahmat *et al*., 2023). Waste management practices have evolved since ancient civilizations, with recycling emerging as a key strategy (Budjav, 2022). Generally, waste is categorized as organic or inorganic. Organic waste includes two subtypes: wet organic waste, such as fruit peels, vegetable residues, and feces, and dry organic waste, including leaves and tree branches (Prodyanatasari *et al*., 2024; Zhang *et al*., 2021). Organic waste is biodegradable and environmentally friendly, yet it must be processed correctly to prevent odor and health risks (Sharma *et al*., 2019; Schiffman *et al*., 2000).

Among sustainable processing strategies, one promising approach is the conversion of wet organic waste into ecoenzymes. This is achieved by fermenting fruit and vegetable peels with molasses and water to produce a dark brown liquid with multi-functional environmental applications. Ecoenzymes can reduce carbon dioxide, heavy metals, and surface pollutants while also promoting soil enrichment and plant health. These attributes make ecoenzyme production both a conservation method and a potential income source.

Numerous studies have employed techno-economic analysis (TEA) to assess waste-based innovations across industries, including waste-to-energy conversion, biogas, bioplastics, and nanoparticle production (Badgett *et al*., 2019; Ou *et al*., 2021; Granata *et al*., 2022; Maratussolihah *et al*., 2022). However, limited scholarly attention has been given to the economic feasibility of ecoenzyme production, especially from wet organic waste at a household or micro-enterprise scale. As shown in **Table 1**, previous TEA studies have explored a wide range of waste applications, but none have specifically addressed ecoenzymes derived from household-level fermentation.

Table 1. Previous studies on TEA.

No	Title	References
1	Computational bibliometric analysis on publication of techno-economic education	(Ragadhita & Nandiyanto, 2022)
2	Techno-economic analysis on the production of zinc sulfide nanoparticles by microwave irradiation method	(Nurdiana *et al*., 2022)
3	Techno-economic evaluation of hyaluronic acid production through extraction method using yellowfin tuna eyeball	(Elia *et al*., 2023)
4	Domestic waste (eggshells and banana peels particles) as sustainable and renewable resources for improving resin-based brakepad performance: Bibliometric literature review, techno-economic analysis, dual-sized reinforcing experiments, to comparison with commercial product	(Nandiyanto *et al*., 2022b)
5	Alternative energy options for a thai durian farm: Feasibility study and experiments for the combination of solar photovoltaics and repurposed lithium-ion batteries	(Wangsupphaphol *et al*., 2024)
6	Feasibility analysis of the development of STEM-based physics e-book with self-regulated learning on global warming topics	(Lestari *et al*., 2024)
7	Techno-economic evaluation of the production of resin-based brake pads using agricultural wastes: Comparison of eggshells/banana peels brake pads and commercial asbestos brake pads	(Ragadhita *et al*., 2023)
8	Aromatic art paper: concept, technology, cost analysis, and application in economic businesses for tourist village communities development	(Rahmawati *et al*., 2025)

Table 1 (Continue). Previous studies on TEA.

No	Title	References
9	Eutectic based ionic liquids betainelevulinic acid: synthesis, physicochemical properties and technoeconomic analysis as lixiviant towards red mud	(Widyaningsih *et al*., 2024)
10	Quantifying the environmental and economic impact of motor vehicle braking: a method for computing energy, fuel, monetary, and carbon dioxide emissions costs	(Teh, 2024)
11	Cost analysis and economic evaluation for tio2 synthesis using sol-gel method	(Nandiyanto *et al*., 2022)

To ensure that this research is well-grounded in scientific trends, a bibliometric analysis was conducted to identify gaps in the literature and highlight the rising global interest in circular waste management, environmental biotechnology, and grassroots innovation. The bibliometric findings validate the novelty of this study and support its relevance in addressing sustainable production methods. **Table 2** shows previous studies regarding bibliometric analysis reports.

This study aims to fill the research gap by conducting a techno-economic analysis of wet organic waste ecoenzyme production, with a 20-year projection, minimal capital investment, and simplified operational models suitable for MSMEs and local communities. In doing so, the research contributes directly to Sustainable Development Goals (SDGs), particularly SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). The model also offers employment potential (SDG 8) and encourages cross-sector partnerships (SDG 17), making it a scalable solution for inclusive environmental conservation.

Table 2. Previous studies on bibliometric analysis reports.

No	Title	References
1	A bibliometric analysis of management bioenergy research using vosviewer application	(Soegoto *et al*., 2022)
2	Oil palm empty fruit bunch waste pretreatment with benzotriazolium-based ionic liquids for cellulose conversion to glucose: Experiments with computational bibliometric analysis	(Mudzakir *et al*., 2022)
3	Research mapping in the use of technology for fake news detection: Bibliometric analysis from 2011 to 2021	(Gunawan *et al*., 2022)
4	Management information systems: bibliometric analysis and its effect on decision making	(Santoso *et al*., 2022)
5	Sustainable Production-inventory model with multi-material, quality degradation, and probabilistic demand: From bibliometric analysis to a robust model	(Utama *et al*., 2023)
6	Phytochemical profile and biological activities of ethylacetate extract of peanut (Arachis hypogaea L.) stems: In-vitro and in-silico studies with bibliometric analysis	(Sahidin *et al*., 2023)
7	Biomass-based supercapacitors electrodes for electrical energy storage systems activated using chemical activation method: A literature review and bibliometric analysis	(Hamidah *et al*., 2023)
8	Antiangiogenesis activity of Indonesian local black garlic (Allium Sativum 'Solo): Experiments and bibliometric analysis	(Arianingrum *et al*., 2023)

Table 2 (Continue). Previous studies on bibliometric analysis reports.

No	Title	References
9	Characteristics of tamarind seed biochar at different pyrolysis temperatures as waste management strategy: Experiments and bibliometric analysis	(Rahmat *et al*., 2023)
10	The compleat lextutor application tool for academic and technological lexical learning: Review and bibliometric approach	(Abduh *et al*., 2023)
11	How eyes and brain see color: Definition of color, literature review with bibliometric analysis, and inquiry learning strategy for teaching color changes to student with mild intelligence barriers	(Juhanaini *et al*., 2023)
12	Corncob-derived sulfonated magnetic solid catalyst synthesis as heterogeneous catalyst in the esterification of waste cooking oil and bibliometric analysis	(Mardiana *et al*., 2024)
13	Prototype of greenhouse effect for improving problem-solving skills in science, technology, engineering, and mathematics (STEM)-education for sustainable development (ESD): Literature review, bibliometric, and experiment	(Solihah *et al*., 2024)
14	Spatial visualization ability assessment for analyzing differences and exploring influencing factors: Literature review with bibliometrics and experiment	(Yang *et al*., 2024)
15	Augmented reality for cultivating computational thinking skills in mathematics completed with literature review, bibliometrics, and experiments for students	(Angraini *et al*., 2024)
16	Low-carbon food consumption for solving climate change mitigation: Literature review with bibliometric and simple calculation application for cultivating sustainability consciousness in facing sustainable development goals (SDGs)	(Nurramadhani *et al*., 2024)
17	Neuroscience intervention for implementing digital transformation and organizational health completed with literature review, bibliometrics, and experiments	(Imaniyati *et al*., 2024)
18	Phylogenetic analysis of Bengkulu citrus based on DNA sequencing enhanced chemistry students' system thinking skills: Literature review with bibliometrics and experiments	(Amida *et al*., 2024)
19	The ship's propeller rotation threshold for coral reef ecosystems based on sediment rate indicators: Literature review with bibliometric analysis and experiments	(Kadir *et al*., 2024)
20	progression: A program evaluation study completed with bibliometric analysis	(Shafiq *et al*., 2024)
21	Android application for smart diagnosis of children with disabilities and its correlation to neuroscience: Definition, literature review with bibliometric analysis, and experiments	(Wagino *et al*., 2024)
22	Deciphering the mechanism of action cosmos caudatus compounds against breast neoplasm: A combination of pharmacological networking and molecular docking approach with bibliometric analysis	(Hendrarti *et al*., 2024)
23	Integration of water heating systems with car air conditioning systems: A bibliometric analysis, lab-scale investigation, and potential applications	(Rusdjijati *et al*., 2025)
24	Optimization of hybrid core designs in 3D-printed PLA+ sandwich structures: An experimental, statistical, and computational investigation completed with bibliometric analysis	(Metteb *et al*., 2025)

Table 2 (Continue). Previous studies on bibliometric analysis reports.

No	Title	References
25	Chemical looping systems for hydrogen production and their implementation in Aspen Plus software: A review and bibliometric analysis	(Vanegas *et al.*, 2025)
26	Dental suction aerosol: Bibliometric analysis	(Ramadhan *et al.*, 2022)
27	Bibliometric analysis of nano metal-organic frameworks synthesis research in medical science using VOSviewer	(Shidiq, 2023)
28	Research trends from the scopus database using keyword water hyacinth and ecosystem: A bibliometric literature review	(Nandiyanto *et al.*, 2024)
29	Use of blockchain technology for the exchange and secure transmission of medical images in the cloud: Systematic review with bibliometric analysis	(Lizama *et al.*, 2024)
30	Chatbot artificial intelligence as educational tools in science and engineering education: A literature review and bibliometric mapping analysis with its advantages and disadvantages	(Al Husaeni *et al.*, 2024a)
31	How technology can change educational research? Definition, factors for improving quality of education and computational bibliometric analysis	(Al Husaeni *et al.*, 2024b)
32	Effects of sustained deficit irrigation on vegetative growth and yield of plum trees under the semi-arid conditions: Experiments and review with bibliometric analysis	(Laita *et al.*, 2024)
33	Hydroxyapatite as delivery and carrier material: systematic literature review with bibliometric analysis	(Noviyanti *et al.*, 2024)
34	Development of intelligent tutoring system model in the learning system of the Indonesian national armed forces completed with bibliometric analysis	(Kurniawan *et al.*, 2024)
35	Artificial intelligence (AI)-based learning media: Definition, bibliometric, classification, and issues for enhancing creative thinking in education	(Solihat *et al.*, 2024)
36	Comprehensive review on wastewater treatment using nanoparticles: Synthesis of iron oxide magnetic nanoparticles, publication trends via bibliometric analysis, applications, enhanced support strategies, and future perspectives	(Mohammed *et al.*, 2025)
37	Role of coastal vegetation belts in mitigating tsunami waves: Bibliometric analysis, numerical, and spatial analysis	(Usman *et al.*, 2025)
38	Synthesis and characterization of acetylene alcohols via alkynylation of heteroatomic aldehydes with phenylacetylene under various reaction parameters completed with spatial chemical structure, literature review, and bibliometric analysis	(Otamukhamedova *et al.*, 2025)
39	How to teach fraction for empowering student mathematics literacy: Definition, bibliometric, and application using digital module	(Farokhah *et al.*, 2025)
40	Smart electric resistance welding based on artificial intelligence (AI) based on real-time adaptive statistical features completed with bibliometric analysis	(Fufon *et al.*, 2025)
41	Research trend on the use of mercury in gold mining: Literature review and bibliometric analysis	(Nandiyanto *et al.*, 2023)
42	How to do research methodology: From Literature Review, Bibliometric, Step-by-step Research Stages, to Practical Examples in Science and Engineering Education	(Susilawati *et al.*, 2025)

2. LITERATURE REVIEW

Ecoenzyme production from organic waste has emerged as a relevant topic within sustainable waste management, offering potential environmental and economic benefits. Previous studies have demonstrated that waste (particularly agricultural and organic byproducts) can be transformed into valuable products such as biogas, compost, and eco-friendly catalysts (Sridevi *et al*., 2024; Mardina *et al*., 2024). While many of these studies apply techno-economic analysis to evaluate the viability of waste-to-product models, the production of ecoenzymes from wet organic waste remains an underexplored area, especially at the household or MSME level.

A growing body of literature emphasizes the importance of ecoenzymes as multi-functional biological solutions. These naturally fermented liquids can reduce chemical pollutants, promote soil fertility, and enhance plant growth. Their use aligns with environmental goals related to pollution reduction and resource circularity (Sharma *et al*., 2019). However, most research to date has focused on the biological efficacy of ecoenzymes, with limited economic modeling or commercialization frameworks available for community-scale implementation.

As shown in **Figure 1**, the standard production flow of ecoenzymes involves mixing wet organic waste (such as fruit and vegetable peels) with water and molasses at a ratio of 10:3:1. The mixture is stored in airtight plastic containers to enable anaerobic fermentation over 100 days. During this time, gas buildup must be periodically released to prevent an explosion, and floating solids are manually pushed downward. Upon completion, the dark brown ecoenzyme liquid is filtered from the remaining solids and stored for use.

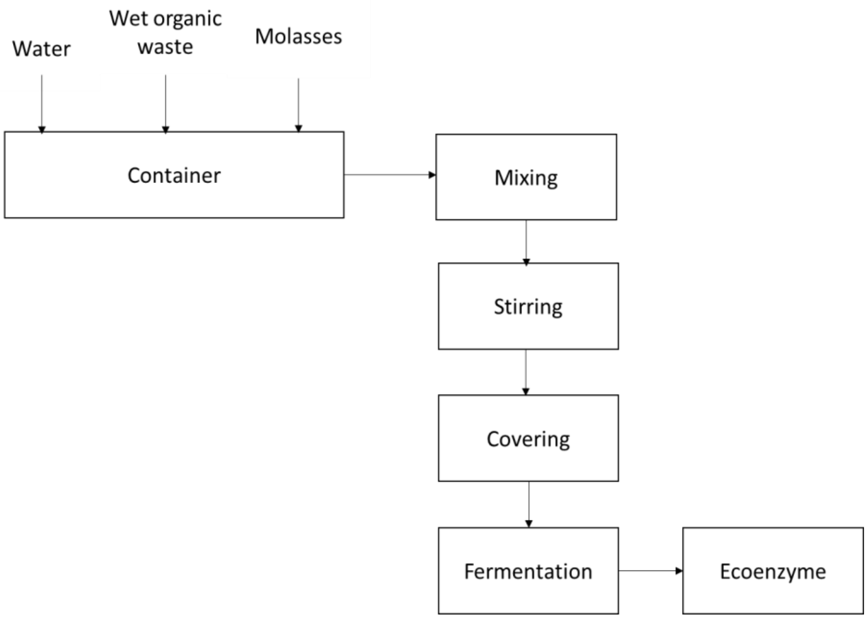

Figure 1. Flowchart of the organic waste ecoenzyme production process.

The practicality of this process makes it particularly suitable for small-scale production using minimal resources. Furthermore, the raw materials (organic waste and water) are freely available in most households, making molasses the only major input cost. The simplicity of the production method, combined with growing market interest in eco-friendly solutions, suggests strong potential for localized ecoenzyme enterprises.

To deepen the theoretical foundation of this study, a bibliometric analysis was conducted to track global research trends in ecoenzyme innovation, waste valorization, and sustainable product development. The analysis revealed a sharp increase in publications between 2019 and 2024 related to organic waste treatment and TEA applications. However, no high-frequency clusters were found around the term "ecoenzyme," highlighting a gap in academic focus. This reinforces the novelty of the current research, as it bridges empirical waste processing with economic evaluation in a domain that has so far received limited scholarly attention.

In summary, existing literature supports the environmental value of waste-derived products and the analytical strength of techno-economic evaluation. However, few studies have combined these elements in the context of wet organic waste-based ecoenzyme production, especially from the perspective of grassroots implementation. This study responds to that gap and proposes a scalable, sustainable, and economically viable solution aligned with both local realities and global sustainability targets.

3. METHOD

This study employed a dual-method approach combining bibliometric analysis and techno-economic evaluation to assess the feasibility of producing ecoenzymes from wet organic waste over a projected 20-year period.

3.1. Bibliometric Analysis

To identify research gaps and confirm the novelty of the proposed topic, a bibliometric review was conducted using the Scopus database. Keywords such as “ecoenzyme,” “organic waste,” “techno-economic analysis,” and “sustainable production” were used to retrieve relevant literature from 2013 to 2024. Analysis was performed using VOSviewer and Bibliometrix tools to explore keyword co-occurrence, research hotspots, publication trends, and frequently cited articles. The results informed the theoretical grounding of this study and confirmed a lack of prior research focused on the techno-economic modeling of household-scale ecoenzyme production. Detailed information on bibliometric analysis is reported elsewhere (Rochman *et al*., 2024; Al Husaeni & Nandiyanto, 2022).

3.2. Techno-Economic Analysis

A techno-economic feasibility assessment was carried out for the production of ecoenzymes from wet organic waste. Detailed information regarding the techno-economic analysis is reported elsewhere (Fiandini & Nandiyanto, 2024).

The model assumes daily production in a simple household or MSME-scale setup, based on three main ingredients: water, wet organic waste, and molasses. While water and organic waste are considered free inputs, molasses was priced using online market data, specifically at $0.26875 per 200 g.

The production plan was modeled across a 20-year lifespan with key assumptions:

(i) One cycle of fermentation requires 100 days.
(ii) Daily production is estimated at 30 L of ecoenzyme liquid.
(iii) The selling price is assumed to be $12.5 per kg.
(iv) Labor is accounted for with three staff roles: marketing, finance, and operations, with a combined monthly incentive of $187.50 per person.
(v) Fixed equipment costs were derived from current online store prices.

Financial feasibility was measured using the following parameters:

(i) CNPV: Cumulative Net Present Value,
(ii) PBP: Payback Period,
(iii) IRR: Internal Rate of Return,

(iv) ROI: Return on Investment,
(v) PI: Profitability Index,
(vi) BEP: Break-Even Point (units), and
(vii) BEC: Break-Even Cost.

A simple mathematical modeling framework was used to simulate revenue and cost streams. Sensitivity analysis was included to evaluate changes in input prices, sales capacity, labor costs, and interest rates, thereby allowing assessment under both normal and stressed conditions.

This methodological framework ensures a well-rounded evaluation that incorporates both scientific relevance through bibliometric insights and financial realism through economic modeling.

4. RESULTS AND DISCUSSION

4.1. Bibliometric Results and Trends in Ecoenzyme and Techno-Economic Research

To understand the scientific context and novelty of this study, a bibliometric analysis was conducted using the Scopus database with the keyword “ecoenzyme” from the years 2012 to 2025. A total of 62 documents were identified over these 14 years. The annual distribution of publications is illustrated in **Figure 2**, which clearly shows an upward trend in scholarly attention, particularly between 2021 and 2024.

The number of publications remained relatively low and stable between 2012 and 2020, averaging fewer than five articles per year. However, a significant increase occurred starting in 2021, with a peak in 2024 at 20 documents. This suggests a rapidly growing interest in ecoenzyme research, likely driven by increasing environmental concerns, the global push toward zero-waste strategies, and the promotion of sustainable alternatives to synthetic chemicals.

Despite this positive trend, the analysis shows that techno-economic studies related specifically to ecoenzyme production from wet organic waste remain scarce. Most retrieved articles focused on the biochemical properties of ecoenzymes or their applications in agriculture and wastewater treatment. Very few examined production scalability, business feasibility, or commercialization models, highlighting a critical gap that this study aims to address.

In addition, co-occurrence mapping (not shown here) revealed that terms such as “fermentation,” “waste management,” and “organic waste” frequently appear, but keywords like “techno-economic,” “feasibility,” or “SDGs” are rarely associated with ecoenzyme studies. This reinforces the novelty of this research in integrating economic modeling with ecological innovation.

Moreover, this trend aligns with broader global priorities such as the United Nations’ SDGs. Research into ecoenzyme production has the potential to contribute to:
(i) SDG 11 (Sustainable Cities and Communities),
(ii) SDG 12 (Responsible Consumption and Production),
(iii) SDG 13 (Climate Action),
(iv) and indirectly to SDG 8 (Decent Work and Economic Growth).

4.2. Financial Assumptions and Production Parameters

The financial assumptions used in this study serve as the foundation for evaluating the techno-economic feasibility of ecoenzyme production from wet organic waste. The goal is to estimate both the investment requirements and the income potential under realistic conditions, particularly for micro and home-based enterprises.

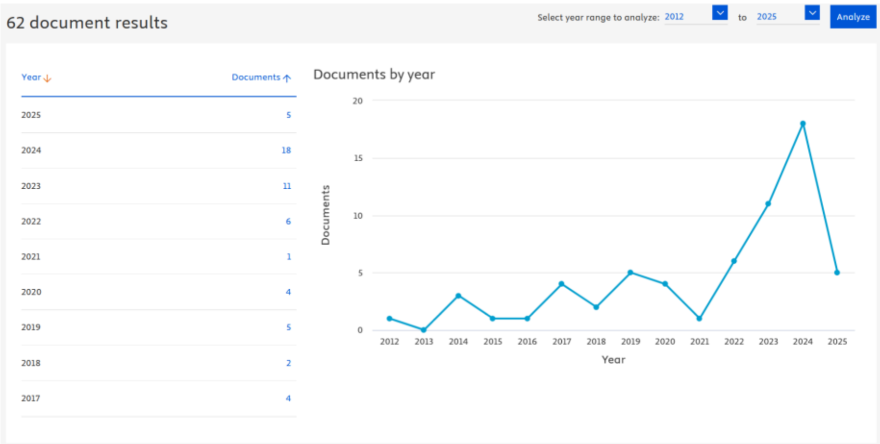

Figure 2. Number of publications indexed in Scopus on "ecoenzyme" from 2012 to 2025, showing a significant rise in interest after 2021 and peaking in 2024.

Several key assumptions were established:

(i) Currency Standard: All economic calculations were performed in USD, with a fixed exchange rate of 1 USD = IDR 16,000.

(ii) Production Capacity: The daily production volume of ecoenzyme was assumed to be 30 L per day, using waste inputs collected from households and rainwater.

(iii) Fermentation Cycle: A single production cycle was assumed to last 100 days, aligning with standard ecoenzyme fermentation practice.

(iv) Raw Materials: The only purchased raw material is molasses, priced at $0.26875 per 200 g, based on commercial online prices. Other inputs (organic waste and rainwater) were assumed to be freely available.

(v) Sales Price: The selling price of the ecoenzyme was set at $12.5 per kg, based on comparable environmentally friendly liquid products in the market.

(vi) Labor Costs: Monthly incentives were assigned to three roles (marketing, finance, and operations), each receiving $187.50, resulting in a total monthly labor cost of $562.50.

(vii) Equipment Costs: All tools and materials (plastic buckets, measuring tools, fermentation containers) were priced based on standard online rates.

(viii) Project Lifetime: The economic projection spans 20 years, reflecting a long-term small business or community initiative model.

To maintain cost efficiency, the production system requires only two 15-L buckets per cycle. Each bucket is filled with a mixture of 1 L of water, 100 g of molasses, and 300 g of organic waste, maintaining the optimal fermentation ratio of 10:3:1. With this structure, the operation is scalable and repeatable every month, with approximately 40 to 50 buckets used concurrently in active fermentation.

These assumptions provide the basis for the full techno-economic model and will inform the profitability indicators, cost structures, and sensitivity analysis in the following sections.

4.3. Cost Structure and Revenue Forecast

Based on the financial assumptions outlined in the previous section, a detailed cost structure was developed to assess the feasibility of wet organic waste ecoenzyme production. The costs are categorized into fixed costs, such as capital investment and depreciation, and variable costs, including raw materials, labor, utilities, and sales-related expenses.

Fixed costs primarily cover long-term equipment investments and are calculated using a straight-line depreciation model. These costs remain stable regardless of production volume. Variable costs, in contrast, depend on the scale and frequency of production cycles.

The summary of production costs and projected revenue is shown in **Table 3**.

Table 3. Summary of techno-economic analysis.

Component	Parameter	Value (USD)
Fixed Cost	Loan Interest	–
	Capital-Related Cost	9,424.51
	Depreciation	810.83
	Total Fixed Cost	**10,235.34**
Variable Cost	Raw Material (Molasses)	80,625.00
	Utilities	1,321.88
	Operating Labor (OL)	2,250.00
	Labor-Related Cost	675.00
	Sales-Related Cost	1,750.00
	Total Variable Cost	**6,077.50**
Revenue	Estimated Sales	25,000.00
	Manufacturing Cost	15,502.01
	Investment	8,690.96
Profit Metrics	Gross Profit	0.38
	Profit to Sales Ratio	1.09

The estimated total manufacturing cost over the modeled period is \$15,502.01, with annual sales revenue projected at \$25,000. This yields a gross profit margin of 38% and a profit-to-sales ratio of 1.09, indicating strong profitability relative to investment.

It is important to note that the only recurring raw material cost is for molasses, while the other components (rainwater and organic waste) are freely available. Labor and sales costs are also kept low, enabling a favorable operational margin.

These financial projections confirm that the ecoenzyme production model is not only feasible but also commercially promising. The next section explores investment viability in greater depth by analyzing the cumulative financial performance over time.

4.4. Profitability Analysis: CNPV, PBP, IRR, ROI, and PI

To assess the long-term financial sustainability of ecoenzyme production, several core economic indicators were applied, including CNPV, PBP, IRR, ROI, and PI. These metrics provide a comprehensive picture of the project's profitability and investment recovery over a 20-year operational horizon.

As illustrated in **Figure 3**, the CNPV/TIC curve reflects the project's performance over time. The graph shows a negative balance in the first three years due to the initial capital and setup costs. However, starting in year 4, the project consistently generates profit, with the CNPV rising steadily throughout the remaining years.

The PBP is calculated at 0.79 years, which is less than one year, a highly favorable timeframe for initial investment recovery. The ROI of 1.17 (or 117%) indicates that the project more than doubles the original capital over time. Additionally, a PI greater than 1.0 confirms that each unit of investment yields positive returns.

The Break-Even Point (BEP) is estimated at 1,081.8 units, showing the minimum quantity of product that must be sold to cover both fixed and variable costs. With an annual projected sales volume well above this threshold, the model offers a significant financial buffer against market fluctuations.

The results also demonstrate that ecoenzyme production aligns well with the principles of the circular economy, minimal waste, high reuse, and scalable returns. Given the low input costs and accessible production model, this initiative can be especially impactful in supporting low-income households or MSMEs in creating both income and environmental value.

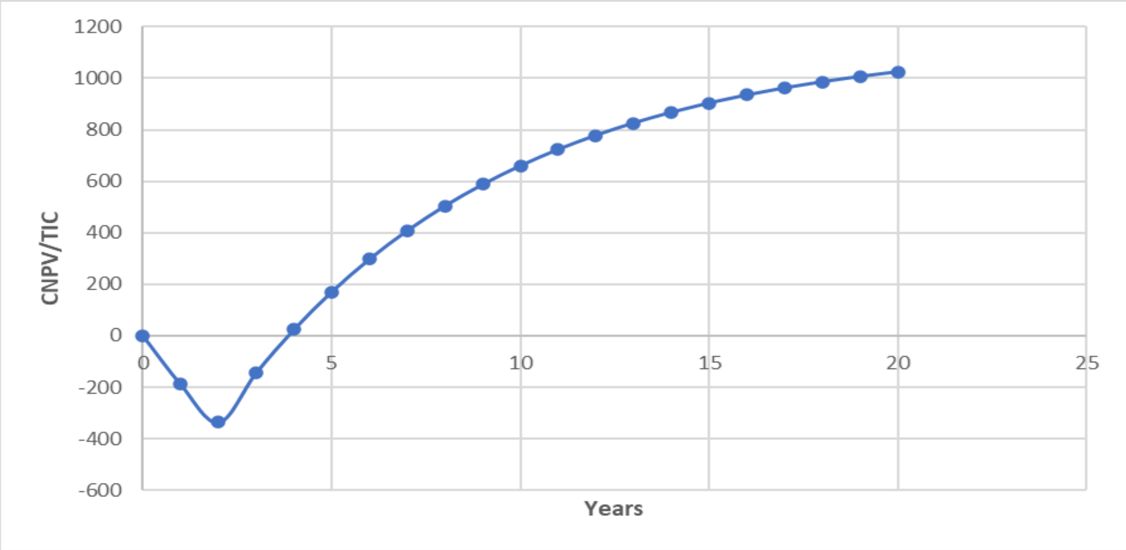

Figure 3. CNPV to TIC ratio over a 20-year period. The graph shows early losses through year 3, followed by sustained profitability from year 4 onward.

4.5. Sensitivity Analysis and Investment Risk Assessment

To test the resilience of the ecoenzyme production model, a sensitivity analysis was conducted. This analysis explores how changes in key financial variables—such as raw material costs, selling price, labor, and production volume—affect the project's profitability indicators. Such assessment is critical for understanding the investment risk, especially for small-scale entrepreneurs with limited capital reserves. Several scenario are in the following:

(i) Scenario 1: Increase in Molasses Price (+25%)
If the price of molasses rises by 25%, the PBP extends from 0.79 to approximately 1.1 years. The CNPV slightly declines, and ROI decreases by 12%. However, profitability remains positive, indicating manageable risk.

(ii) Scenario 2: Drop in Selling Price (–20%)
A reduction in the product's market price from $12.5 to $10 per kg results in a significant dip in ROI and prolongs the PBP to nearly 2 years. The project remains viable but operates closer to the break-even point, requiring tighter cost control.

(iii) Scenario 3: Labor Cost Increase (+30%)
If incentives or staffing costs increase by 30%, the overall impact on profitability is minimal due to the relatively small share of labor in the cost structure. ROI drops marginally, but the PI remains above 1.0, preserving the investment's attractiveness.

(iv) Scenario 4: Reduced Daily Output (–25%)
A production drop from 30 to 22.5 L/day extends the PBP beyond 1.5 years and causes a sharper decline in NPV. This scenario underlines the importance of maintaining consistent production capacity and raw material availability.

(v) Scenario 5: Delay in Market Entry (1-year delay)

If the business starts a year later, without offsetting changes in pricing or policy support, the overall investment return is deferred. Inflation and opportunity cost increase, but the long-term profitability trajectory remains strong if market demand is stable.

These simulations confirm that while the ecoenzyme project is robust, its profitability is moderately sensitive to pricing dynamics and production efficiency. Mitigating these risks can be achieved through:

(i) Long-term procurement contracts for molasses,
(ii) Community-based collection systems for organic waste,
(iii) Local government incentives (e.g., tipping fees or tax exemptions),
(iv) Diversification of ecoenzyme applications (e.g., agriculture, cleaning, cosmetics).

Overall, the model demonstrates a low-risk profile with high adaptability, making it a promising candidate for sustainable micro-enterprise development.

4.6. Policy Implications and Contributions to SDGs

The results of this study offer substantial policy implications for environmental sustainability, waste management reform, and micro-enterprise empowerment. Given the simplicity and low capital requirements of ecoenzyme production from wet organic waste, local governments, NGOs, and development agencies can adopt this model as a scalable, community-based environmental solution.

From a regulatory standpoint, ecoenzyme production supports the national agenda on zero waste, waste segregation, and climate-smart initiatives. The decentralized nature of the model makes it ideal for integration into local waste management systems, especially in urban and peri-urban areas with limited access to centralized recycling infrastructure.

Supportive policies could include:

(i) Training programs for MSMEs and households on ecoenzyme production,
(ii) Procurement frameworks for using ecoenzymes in public parks, sanitation, or agriculture,
(iii) Microfinance or grant mechanisms to assist with startup equipment costs,
(iv) Tax relief or carbon credit schemes for businesses engaged in organic waste recovery.

This research also contributes directly to the advancement of several United Nations SDGs:

(i) SDG 11: Sustainable Cities and Communities: The model reduces landfill dependency and promotes local environmental action.
(ii) SDG 12: Responsible Consumption and Production: Ecoenzyme production exemplifies circular economy principles by converting waste into valuable inputs.
(iii) SDG 13: Climate Action: The fermentation process helps reduce methane emissions from unmanaged organic waste and supports low-carbon lifestyles.
(iv) SDG 8: Decent Work and Economic Growth: The model enables income generation for underemployed groups without requiring advanced skills.
(v) SDG 17: Partnerships for the Goals: Its success depends on collaboration between households, local governments, universities, and the private sector.

By combining low-cost technology, grassroots accessibility, and environmental benefits, the ecoenzyme production model provides a replicable, scalable, and impactful solution. It encourages community participation, environmental awareness, and sustainable livelihoods, all central to long-term development planning. Finally, this study adds new information regarding SDGs, as reported elsewhere (**Table 4**).

Table 4. Previous studies on SDGs.

No	Title	References
1	Low-carbon food consumption for solving climate change mitigation: Literature review with bibliometric and simple calculation application for cultivating sustainability consciousness in facing sustainable development goals (SDGs)	(Nurramadhani *et al.*, 2024)
2	Towards sustainable wind energy: A systematic review of airfoil and blade technologies over the past 25 years for supporting sustainable development goals (SDGs)	(Krishnan *et al.*, 2024)
3	Assessment of student awareness and application of eco-friendly curriculum and technologies in Indonesian higher education for supporting sustainable development goals (SDGs): A case study on environmental challenges	(Djirong *et al.*, 2024)
4	A study on sustainable eggshell-derived hydroxyapatite/CMC membranes: Enhancing flexibility and thermal stability for sustainable development goals (SDGs)	(Waardhani *et al.*, 2025)
5	Effect of substrate and water on cultivation of Sumba seaworm (nyale) and experimental practicum design for improving critical and creative thinking skills of prospective science teacher in biology and supporting sustainable development goals (SDGs)	(Kerans *et al.*, 2024)
6	Characteristics of jengkol peel (pithecellobium jiringa) biochar produced at various pyrolysis temperatures for enhanced agricultural waste management and supporting sustainable development goals (SDGs)	(Rahmat *et al.*, 2025)
7	Sustainable packaging: Bioplastics as a low-carbon future step for the sustainable development goals (SDGs)	(Basnur *et al.*, 2024)
8	Smart learning as transformative impact of technology: A paradigm for accomplishing sustainable development goals (SDGs) in education	(Makinde *et al.*, 2024)
9	The relationship of vocational education skills in agribusiness processing agricultural products in achieving sustainable development goals (SDGs)	(Gemil *et al.*, 2024)
10	The influence of environmentally friendly packaging on consumer interest in implementing zero waste in the food industry to meet sustainable development goals (SDGs) needs	(Haq *et al.*, 2024)
11	Implementation of sustainable development goals (SDGs) no. 12: Responsible production and consumption by optimizing lemon commodities and community empowerment to reduce household waste	(Maulana *et al.*, 2023)
12	Analysis of the application of mediterranean diet patterns on sustainability to support the achievement of sustainable development goals (SDGs): Zero hunger, good health and well beings, responsible consumption, and production	(Nurnabila *et al.*, 2023)
13	Efforts to improve sustainable development goals (SDGs) through education on diversification of food using infographic: Animal and vegetable protein	(Awalussillmi *et al.*, 2023)
14	Safe food treatment technology: The key to realizing the sustainable development goals (SDGs) zero hunger and optimal health	(Rahmah *et al.*, 2024)
15	Analysis of student's awareness of sustainable diet in reducing carbon footprint to support sustainable development goals (SDGs) 2030	(Keisyafa *et al.*, 2024)

5. CONCLUSION

This study has presented a comprehensive techno-economic and bibliometric analysis of ecoenzyme production from wet organic waste. The findings confirm that the model is technically simple, economically viable, and socially scalable, particularly for small businesses and household-level operations. The production process requires minimal capital, utilizes easily accessible raw materials, and results in a multi-purpose environmental product. The techno-economic model, projected over a 20-year timeline, demonstrates strong profitability. Key indicators such as Payback Period (0.79 years), ROI (117%), and a positive CNPV trajectory confirm the financial viability of the venture. Sensitivity analysis further affirms that the model remains resilient under variable cost and market scenarios, although optimal outcomes depend on maintaining production consistency and pricing stability. The bibliometric analysis highlights a growing academic interest in waste valorization, though the specific application of techno-economic analysis to ecoenzyme production remains limited. This gap reinforces the novelty and relevance of the present study. Importantly, the proposed ecoenzyme model directly supports several SDGs, including SDG 11 (sustainable cities), SDG 12 (responsible consumption), SDG 13 (climate action), SDG 8 (decent work), and SDG 17 (partnerships). It offers a practical and scalable solution for addressing urban waste problems while empowering communities and micro-entrepreneurs. Future research is recommended to explore the biochemical optimization of ecoenzymes, the development of market networks, and integration with policy frameworks to support larger-scale deployment.

6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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