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Recycling Pesticide Plastic Containers in Indonesia: An Evaluation of Technical, Economic, and Regulatory Impact Feasibility

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ABSTRACT: This study explores the feasibility of recycling pesticide plastic packaging in Indonesia, focusing on technical, economic, and regulatory aspects. Technical feasibility analysis highlights challenges in material composition and pesticide residue removal, emphasizing the effectiveness of a cleaning process to ensure safety and quality of recycled materials. Economically, the study demonstrates significant cost savings when incorporating at least 40% recycled material into new packaging, enhancing market competitiveness. The regulatory analysis emphasizes the recommendation to the Indonesian government to reclassify waste pesticide containers from hazardous to non-hazardous materials following the validation of the triple rinsing trial's effectiveness in removing pesticide residue. Reclassifying the containers as non-hazardous will reduce transportation costs from the source locations, such as plantations or farming areas, to the waste processing plant, thereby improving the economic feasibility of the pesticide plastic container recycling. Recommendations include conducting production trials with larger container sizes and adjusting the recycled material percentage, as well as exploring performance-enhancing additives for recycled plastics. Industries are advised to align with regulations by adopting best recycling practices and establishing robust compliance processes. Strengthening Extended Producer Responsibility (EPR) schemes and supporting advanced recycling infrastructure development are critical steps. These measures will improve the efficiency and effectiveness of recycling programs, ensuring regulatory compliance and promoting sustainable waste management. The study concludes that recycling pesticide plastic packaging is feasible and beneficial, provided that technical and economic challenges are effectively addressed with at least 40% recycled material content. The economic viability of recycling pesticide plastic containers will be further enhanced if the Indonesian government reclassifies the waste containers as non-hazardous, after triple rinsing process, thereby reducing transportation costs.

KEYWORDS: Extended Producer Responsibility (EPR), Economic feasibility, Pesticide packaging recycling, Regulatory compliance, Triple rinsing.

1. INTRODUCTION

Plastic packaging has become an integral component of the modern agrochemical sector, particularly in the packaging of pesticides and agrochemical-related products. The use of plastics in pesticide packaging offers numerous advantages, including cost-effectiveness, durability, and product protection. However, the widespread use of plastic containers in this industry has led to significant environmental concerns due to the persistence and potential harm of plastics in the ecosystem (Rajmohan et al., 2019). The global pesticide industry plays a crucial role in agricultural productivity, ensuring food security, and supporting the livelihoods of millions of farmers worldwide. As the demand for pesticides continues to rise to meet the challenges of global food production, so does the volume of plastic packaging waste generated. This waste poses a multifaceted challenge encompassing environmental pollution, resource inefficiency, and health concerns (Sridharan et al., 2021).

The project to recycle pesticide plastic containers involves developing a solid management structure on pesticide plastic packaging waste collection and recycling systems within pesticide industries. This is achieved through comprehensive surveys of social practices and legal requirements for using and disposing of plastic containers in firms involved in the production of agrochemicals. Moreover, the project aims to research modern techniques of mechanical recycling and good practices from foreign countries that could be introduced to Indonesia (Thompson & Darwish, 2019). The issue of plastic waste is a global phenomenon with far-reaching consequences. Plastics are known for their persistence in the environment, taking hundreds of years to degrade fully. Improper disposal and mismanagement of plastic waste have led to widespread pollution, detrimentally impacting terrestrial and aquatic ecosystems (Rajmohan et al., 2019).

The significant usage of plastic containers in Indonesia's pesticide sector has led to an alarming increase in plastic waste. This issue poses several environmental, financial, and legal challenges for the country. Improper disposal of plastic pesticide containers results in land and water pollution, with chemicals leaching into the soil and water sources, affecting crop production and quality (Dhananjayan et al., 2019). Additionally, burning these containers releases harmful pollutants, contributing to air pollution and health risks (Rajmohan et al., 2019).

The financial impact includes substantial costs for waste management and cleanup, affecting both governmental and private sectors. Tourism and agriculture are also negatively impacted, with plastic pollution deterring visitors and reducing crop yields and quality (Koul et al., 2021). Furthermore, regulatory gaps and compliance costs pose significant challenges for pesticide companies, while international pressure on Indonesia to manage plastic waste effectively can affect its trade relationships and economic growth (Shittu et al., 2020).

The improper management of pesticide plastic container waste in the Indonesian pesticide sector manifests in various ways. Pesticide containers are frequently disposed of without following proper procedures, leading to environmental pollution. There is a lack of effective recycling activities and limited initiatives, resulting in missed opportunities for resource recovery. Additionally, current laws may not adequately address the unique challenges posed by pesticide plastic container waste, and there is a lack of awareness among farmers and other stakeholders about proper waste management practices and the benefits of recycling (Thompson & Darwish, 2019).

This study aims to define the viability of the recycling process for pesticide plastic containers in Indonesia based on three key objectives. First, assess the technical challenges and barriers associated with recycling pesticide plastic packaging materials, including issues related to material composition and pesticide residue. Develop practical recommendations for optimizing the recycling process to ensure the safe and efficient transformation of pesticide plastic packaging into reusable materials. Second, compare the costs of recycling with the normal production process using virgin materials, quantifying potential cost savings and economic advantages. Conduct a comprehensive cost-benefit analysis of implementing recycling programs for pesticide plastic packaging within the Indonesian pesticide industry. Third, analyze the existing regulations and policies related to pesticide plastic packaging waste in Indonesia and their impact on recycling feasibility. Propose recommendations for government policies to promote the economic feasibility of recycling pesticide plastic packaging.

The scope of this research includes a comprehensive analysis of the current state of pesticide plastic container waste management in Indonesia, identifying key challenges and opportunities, and proposing sustainable solutions. The research will focus on technical, economic, and regulatory aspects, drawing from case studies and best practices from other countries. However, the study may be limited by the availability of data, the willingness of stakeholders to participate, and potential changes in regulatory frameworks during the research period.

2. LITERATURE STUDY

2.1 Plastic Waste Management in Agriculture

Plastic packaging is essential to contemporary agriculture since it provides diverse agricultural items like insecticides, fertilizers, and seeds with protection, convenience, and durability (Lakhiar et al., 2024). Because they can effectively distribute and store products, avoid contamination, and maintain product quality, plastic containers, bags, and wraps are becoming widely used in the agriculture industry. The secure delivery of agricultural inputs from producers to final consumers, such as farmers and agricultural enterprises, is ensured by plastic packaging. Furthermore, because plastic materials can be tailored to fit the specific demands of the agricultural business, they are versatile and adaptable to different packaging requirements. However, there are serious environmental problems resulting from the extensive use of plastic packaging in agriculture, especially with regard to managing plastic waste (Shah & Wu, 2020). Because it may linger in the environment for hundreds of years and build up in landfills, water bodies, and natural habitats, plastic trash is a hazard to ecosystems, animals, and human health.

Degradation of soil, water, and air quality is a result of improper disposal of plastic trash, which includes burning and littering. These actions also worsen environmental contamination. Economic costs for farmers and communities can result from the buildup of plastic garbage in agricultural regions, which can also reduce crop growth and agricultural production. Worldwide, the notion of plastic waste management has gained popularity in the agricultural industries as a reaction to these environmental issues. The term "plastic waste management" refers to a variety of techniques and approaches meant to decrease the environmental effect of plastic materials through reduction, recycling, and reuse. Recycling, in particular, is essential for minimizing the negative effects of plastic waste on the environment since it keeps the garbage out of landfills and incinerators, conserves natural resources, and lowers greenhouse gas emissions (Kibria et al., 2023).

2.2 Plastic Packaging Recycling

Recycling plastic packaging aligns well with the principles of the circular economy, which promote resource reuse and continuous usage to reduce waste and increase resource efficiency. Recycling plastic packaging is essential to complete the material flow loop in a circular economy, which involves designing, producing, using, and then reintegrating items as raw materials into new products (Chioatto & Sospiro, 2022). Stakeholders can lessen the amount of virgin materials extracted, use less energy, and lessen environmental damage related to the manufacture and disposal of plastics by recycling plastics. Recycling plastic packaging while adhering to the principles of the circular economy not only supports environmental sustainability but also resilience and economic growth by opening up new avenues for value creation, innovation, and employment.

Plastic recycling is an attractive answer to the problems associated with managing plastic trash since it has positive effects on the environment and the economy. Recycling plastics benefits the environment by preserving natural resources, lowering energy usage, and reducing greenhouse gas emissions brought on by the manufacture of virgin materials. Recycling also contributes to the reduction of environmental pollution and safeguards ecosystems, animals, and public health by keeping plastics out of landfills and incinerators. Furthermore, recycling helps to maintain habitats and biodiversity, which in turn ensures the long-term viability of natural ecosystems (Nasrollahi et al., 2020).

2.3 Recycling Pesticide Plastic Packaging

To guarantee the efficiency and security of the recycling process, a number of technical issues with plastic packaging for pesticides need to be resolved. The varied material composition of plastic pesticide containers, which might comprise a range of plastic types with distinct qualities and additives, presents a serious difficulty. The existence of many plastic kinds makes it more difficult to sort and process plastic garbage, in order to separate and recycle each item efficiently, specific tools and methods are needed. Furthermore, pesticide residues that are left in the containers provide a danger of contamination since they might contaminate recycled materials or cause issues for the recycling process. This research focuses on a closed-loop plastic recycling process, which involves recycling waste pesticide plastic containers to be used as additional plastic material for the same product. This approach will ensure color stability and material homogeneity of the plastic containers.

Strict cleaning and decontamination protocols are needed to manage pesticide residue contamination, which complicates and increases the cost of recycling by ensuring the safety and quality of recycled materials (Picuno et al., 2020). Implementing recycling systems for plastic packaging used in pesticides presents both technical and financial obstacles that must be solved in order to achieve profitability and sustainability.

The high cost of recycling infrastructure and technology, which includes tools for collecting, sorting, processing, and reprocessing as well as running costs for personnel, upkeep, and transportation, is a significant hurdle (Hagelüken & Goldmann, 2022). Small-scale or resource-constrained stakeholders may find it difficult to make the initial investment necessary to set up recycling facilities and activities, which would limit their capacity to take part in recycling programs. Additionally, the market's demand for recycled materials determines whether recycling operations are financially feasible. This demand might change depending on a number of variables, including consumer preferences, commodity prices, and legal requirements. It takes extensive cost-benefit analysis, market research, and strategic planning to identify and overcome financial obstacles and feasibility difficulties in order to ensure the profitability and long-term viability of recycling initiatives.

2.4 Innovation in Recycling Technologies

Technological advancements in recycling are essential for tackling the special qualities of plastic pesticide containers and enhancing the efficacy and efficiency of recycling plastic packaging trash. Creating specific recycling technologies and procedures suited to the particular characteristics and difficulties of pesticide plastic containers is one area of innovation. These innovations might include sophisticated sorting systems that use artificial intelligence algorithms and sensors to recognize and separate various plastics, including pesticide containers, according to factors like color, shape, and material composition. Furthermore, cutting-edge methods of disinfection and cleaning, like chemical treatments, hot washing, and sterilizing procedures are being created to efficiently eliminate pollutants and pesticide residues from plastic containers (Li et al., 2022).

The recycling of discarded plastic packaging, particularly pesticide containers, is improving due to technological advancements in material sorting, cleaning, and processing. Technologies for material sorting, such automated sorting robots and optical sorting systems, allow plastic waste streams to be quickly and precisely separated, boosting recycling operations' productivity and efficiency. In order to ensure the purity and quality of recycled materials, cleaning technologies, such as solvent- and water-based cleaning systems, are being developed to remove pollutants and impurities from plastic surfaces. Furthermore, recycled plastics may be processed using technologies like extrusion, injection molding, and compression molding to create new goods and packaging materials that have qualities and performances similar to those of virgin plastics. These developments in material sorting, cleaning, and processing technologies facilitate the shift to a circular economy and increase the sustainability and scalability of recycling waste plastic packaging (Petruk et al., 2020).

2.5 Regulatory Framework in Plastic Waste Management

The regulatory framework that oversees the management and recycling of plastic trash in Indonesia comprises a range of laws, rules, and policies that are designed to reduce pollution to the environment, encourage sustainable waste management practices, and facilitate the shift towards a circular economy. Law No. 18 of 2008 on Waste Management, which establishes the legal framework for waste management operations such as collection, transportation, treatment, and disposal, is a crucial law pertaining to the management of plastic trash. This legislation requires stakeholders to prioritize waste minimization and recycling initiatives in order to avoid environmental consequences. It highlights the notion of waste reduction, reuse, and recycling. Indonesia has particular laws and policies addressing plastic waste in addition to general waste management laws. One such law is Government Regulation No. 81 of 2012 on Household Waste Management, which requires the separation of plastic waste from household waste streams in order to be recycled. Furthermore, with the goal of achieving a 70% reduction in plastic waste by 2025, Presidential Regulation No. 97 of 2017 on National Waste Management Policy sets aggressive objectives for lowering the creation of plastic trash and raising recycling rates (Hossain et al., 2022). Enforcing environmental legislation and encouraging sustainable waste management techniques are crucial roles played by government agencies in guaranteeing stakeholder responsibility and compliance.

The main regulatory body in charge of monitoring waste management initiatives and enforcing environmental laws pertaining to plastic trash is the Ministry of Environment and Forestry (MOEF). In order to create and carry out waste management strategies, programs, and initiatives, such as public awareness campaigns and recycling programs for plastic trash, MOEF works in partnership with regional governments, local authorities, and other stakeholders. In order to ensure the safety and quality of recycled products, promote best practices in waste management, and develop standards and rules for plastic waste management and recycling, government bodies are essential. In addition, regulatory bodies oversee and uphold adherence to environmental laws by carrying out examinations, assessments, and legal measures to rectify infractions and guarantee responsibility among interested parties. Government officials may assist Indonesia's transition to sustainable plastic waste management practices and the growth of a circular economy by encouraging regulatory compliance and stakeholder participation (Martin et al., 2023).

2.6 Research Framework

The proposed process for recycling pesticide plastic packaging involves key stakeholders: farmers, waste processors, and plastic packaging manufacturers, all playing critical roles in ensuring the recycling process is technically and economically feasible. Plastic containers for pesticides must be decontaminated before recycling, with the triple-rinsing method as the initial step to clean pesticide residue (Picuno et al., 2020). Although triple-rinsing alone is often insufficient, an additional washing phase can achieve higher decontamination levels. Farmers' support and commitment to triple-rinsing are crucial as the initial stage of ensuring no pesticide residue. Advanced cleaning at the waste processor's site includes solvent-based chemical cleaning, shredding, surfactant washing, pressurized water cleaning, and pelletizing to convert the plastic into granules, which are then sent to manufacturers. These steps are sufficient to ensure recycled material meets specifications for packaging production. At the manufacturer's factory, recycled material is used for container production, with quality control ensuring the recycled plastic's properties are within acceptable limits (Briassoulis et al., 2012). The process's economic feasibility is determined by comparing the cost savings from using recycled material against the costs of collecting and cleaning pesticide packaging waste, including logistics costs.

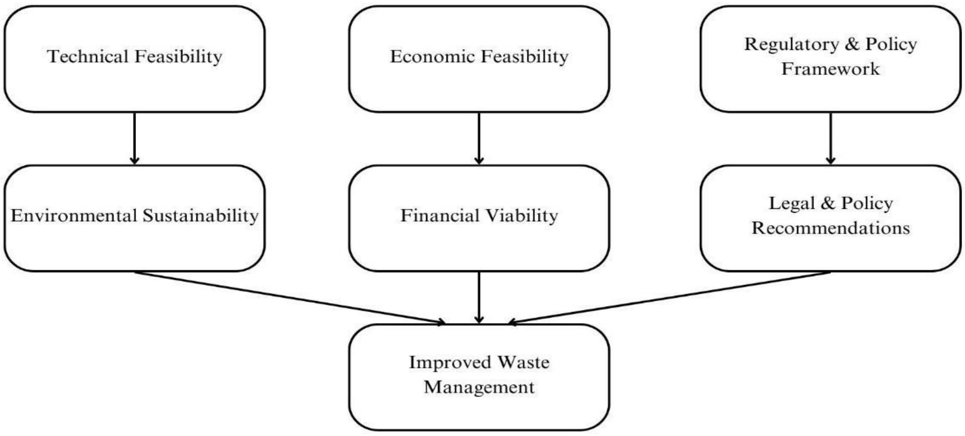


Figure 1. Conceptual Framework

3. RESEARCH DESIGN

3.1 Research Method

To measure the effectiveness of the cleaning process, laboratory tests are conducted to determine the presence and level of pesticide active ingredients after farmers' triple rinsing and waste processors' cleaning procedures. Using Gas Chromatography or HPLC equipment, the analysis involves soaking shredded recycled material in water or solvent, depending on the product, and testing the rinsate for active ingredients. If detected, it indicates the cleaning process is insufficient and needs refinement (Picuno et al., 2020). The steps include soaking the material, conducting GC or HPLC tests, and analyzing the graph patterns to assess the cleaning process's effectiveness. For determining the acceptable percentage of recycled material in pesticide containers, production trials with 30%, 40%, and 50% recycled content are conducted. Quality checks and compatibility tests, including top load, rigidity, drop, weight, dimensions, and leaking tests, assess the impact of recycled material on overall packaging performance and product quality.

The environmental assessment involves controlled lab experiments to test the effectiveness of washing procedures in eliminating toxic pesticide residues from plastic containers. Financial analysis calculates the overall recycling process cost per kilogram, including transport, cleaning, and processing fees, and compares it to the cost of manufacturing containers from raw materials. Legal evaluation assesses the effectiveness of the triple cleansing process in eliminating contaminants, with the aim of reclassifying pesticide container waste as non-hazardous B3 waste. This involves rigorous washing to ensure products are devoid of pesticide residues and empirical evidence to support legislative changes. Government regulations are crucial in defining logistics standards, especially for collecting and transporting used containers from farmers to waste processors. The policy evaluation observes existing regulations' support for recycling efforts and provides recommendations for enhanced governmental support to ensure the sustainability of the recycling program. Reviewing similar international programs can offer insights into constructive steps toward protecting the environment and achieving economic feasibility in recycling pesticide containers.

3.2 Data Collection

Data collection in this study involves testing the cleaning effectiveness of pesticide-contaminated containers and validating the use of recycled material in new containers. Containers previously exposed to pesticides undergo a washing process to reduce residue. Samples are checked for pesticide residue before and after washing to confirm the cleaning process's effectiveness. Recycled material usage is tested in containers with 30%, 40%, and 50% recycled content, assessing specifications to ensure they meet industry standards. This analysis determines whether recycled material impacts container quality and functionality.

Financial data collection identifies the economic potential of using recycled materials in container production, comparing costs of recycled and virgin materials. This analysis includes reagent, transport, and washing expenses, aiming to establish if recycled materials are cost-effective while meeting quality standards. The financial viability of using recycled materials in manufacturing is assessed in terms of cost, profits, and efficiency gains.

Legal data collection focuses on regulations for reusing pesticide containers and potential lobbying to allow their use. This includes advocating for a triple washing process to reclassify containers as non-hazardous waste, potentially reducing transport costs. The analysis reviews existing legislation and explores avenues for new policies to support recycled materials in pesticide production. Two Focus Group Discussions (FGDs) provided insights into stakeholder perspectives and regulatory frameworks, contributing qualitative information for the study. The findings will inform additional analysis and recommendations.

3.3 Analysis Technique

This study follows a four-stage process, with the final stage summarizing the technical and financial analysis to determine the feasibility of recycling plastic pesticide containers. The stages are: validation of the treatment process for recycled pesticide containers, production trials of pesticide plastic containers with recycled material, observation of Indonesian government regulations and policies, and a review of the overall technical and economic feasibility.

The process begins with collecting waste plastic containers from farmers, followed by sampling at four critical points: waste source, pre-cleaning, post-cleaning, and recycled container testing. The containers undergo triple rinsing and washing, including shredding, washing with water and surfactants, and drying. Laboratory analysis using Gas Chromatography or HPLC equipment measures the active ingredient content to assess cleaning efficiency and material suitability for recycling. Production trials at plastic container manufacturers test recycled material percentages of 30%, 40%, and 50%, with quality control and compatibility tests to ensure packaging standards and pesticide product integrity.

Government policy evaluation includes environmental, financial, and legal assessments. Controlled lab experiments test the effectiveness of washing procedures in eliminating toxic residues. Financial analysis calculates the overall recycling process cost, comparing it to manufacturing costs from raw materials. Legal evaluation assesses the triple cleansing process's effectiveness in reclassifying pesticide container waste as non-hazardous B3 waste. Reviewing similar international programs provides insights into enhancing Indonesian government support for sustainable recycling efforts.

The research framework integrates technical feasibility, economic viability, and regulatory considerations, guiding data collection, analysis, and reporting. The final analysis synthesizes findings from technical and cost factors, leading to recommendations for improving waste management systems and the feasibility of recycling pesticide plastic packaging in Indonesia.

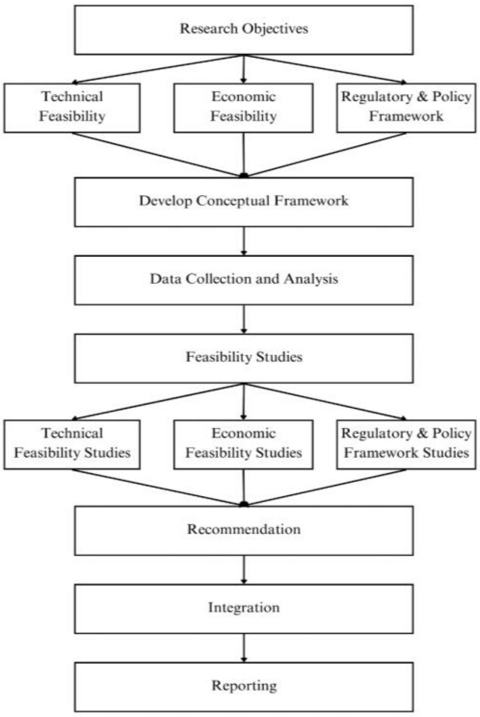


Figure 2. Research Framework

4. RESULT AND DISCUSSIONS

4.1 Technical Feasibility

The technical feasibility assessment involves three main stages: Waste Collection, Cleaning Process, and Packaging Manufacturing Trial. Over 100 kg of pesticide containers were collected and sent to a certified waste processing company in Purwakarta, West Java, Indonesia for further recycling process. At the waste processing plant, the containers were cut and shredded into flakes, then washed with a 0.1% surfactant solution. The flakes were subsequently rinsed with clean water to remove any surfactant residue, and then continued by drying process to reduce the water content. This overall cleaning process took approximately five days. The clean flakes were then used in a manufacturing trial at a plastic packaging factory in Tangerang, Banten, Indonesia, to produce 100mL bottles with different recycled material content ratios (30:70, 40:60, and 50:50 of recycled to virgin material). The purpose of this trial was to test the feasibility of applying various proportions of recycled materials into new pesticide containers. Although the actual pesticide pack size is 20 liters, the research used 100mL bottles due to the limited number of waste pesticide containers collected from the plantation locations.

4.1.1 Effectiveness of cleaning process

The cleaning process's effectiveness was evaluated through visual observation and residual pesticide content analysis. Initial samples from the Jerry cans showed a cloudy liquid, indicating pesticide residues. After the cleaning process with water, the rinsate liquid turned clear, indicating a reduction in contamination. Further washing with liquid soap confirmed complete residue removal, as evidenced by the clear solutions in subsequent samples. The liquid from the soaking water of shredded recycled plastic was then tested in the pesticide company's laboratory using Gas Chromatography equipment to validate the residual content of the pesticide's active ingredient in the recycled material.

Gas Chromatography analysis of the samples initially confirmed the presence of detectable pesticide active ingredients, indicating significant contamination. However, after the proper cleaning process, which involved initial rinsing with water and subsequent washing with surfactant solution, no pesticide residues were found. This confirmed the effectiveness of the cleaning procedure in eliminating pesticide residues from the recycled material. The clear liquids observed in the samples post-cleaning further confirmed that the rinsing method, followed by an additional washing with liquid soap, effectively removed all pesticide residues. This multi-step cleaning process ensures that the recycled plastic flakes meet quality standards, making the containers suitable for recycling and reuse in new pesticide packaging.

Table I. Pesticide Residual Content Analysis

Sample Code	Sample Condition	Sample Treatment	Run Time	Area	Result (ppm)	Conclusion
Jerry can 1.1	2 Jerry cans, Initial Sample (Before Rinsing by Water)	Sample are added by 10 L water each, shake, take the rinsing water for Residual AI analysis	2.007	573.49	620.6309	Positive AI Residual content is detected
Jerry can 2.1			2.008	581.46	629.2304	Positive AI Residual content is detected
Jerry can 1.2	2 Jerry cans, Triple Rinsing, Sample after 3 times rinsing by water 10 L each (water only)	Sample are added by 10 L water each, shake, and throw away the rinse water. Do the same treatment 3 times. Add 10 L water, shake, and take the rinsing water for Residual AI analysis	-	-	0.0000	Negative AI Residual content eliminated
Jerry can 2.2			-	-	0.0000	Negative AI Residual content eliminated

Jerry can 1.3	2 Jerry cans, Triple rinsing; Sample after 3 times rinsing by water 10 L each and 1 time rinse using liquid soap (water + surfactant)	Sample after rinse by 3 times water, then add liquid soap for additional cleaning and rinse by water until it's soap free. Add 10 L water, shake , and take the rinsing water for Residual AI analysis	-	-	0.0000	Negative AI Residual content eliminated
Jerry can 2.3			-	-	0.0000	Negative AI Residual content eliminated
Dry Shredded packaging without washing	The initial jerry-can was shredded, without washing	Sample was soaked in water and sonicated for 15 minutes	2.011	118.80	129.9944	Positive AI Residual content is detected
Dry Shredded packaging after washing	The initial jerry can is shredded and washed manually with water	Sample was soaked in water and sonicated for 15 minutes	-	-	0.0000	Negative AI Residual content eliminated
Shredded; wet; no water rinsing	The initial jerry can is shredded and washed with soap-water (without rinsed with water)	Sample was soaked in water and sonicated for 15 minutes	-	-	0.0000	Negative AI Residual content eliminated
Shredded; dry; with water rinsing	The initial jerry- can is shredded and washed with soap-water using a machine, and rinsed with water	Sample was soaked in water and sonicated for 15 minutes	-	-	0.0000	Negative AI Residual content eliminated

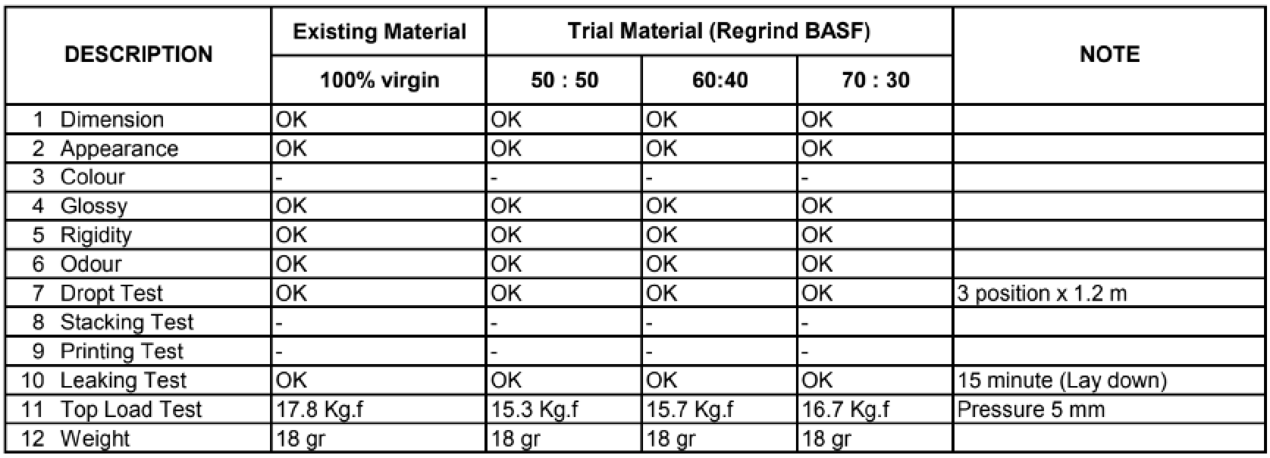
4.1.2 Assessing performance of plastic packaging with recycled material

The performance of plastic packaging incorporating recycled material was evaluated through permeability tests and quality control assessments. Permeability tests with varying ratios of recycled content (30%, 40%, 50%) indicated that most samples maintained integrity, with minimal to no weight loss. However, one sample with 40% recycled content exhibited an abnormal permeation rate, possibly due to material distribution inconsistencies, defects, or testing errors. This highlighted the need for careful monitoring and control during the production process.

Quality control tests, including assessments of dimensions, appearance, rigidity, drop resistance, leakage, and top load capacity, confirmed that the recycled material performed comparably to virgin material. The test results showed that containers made with up to 50% recycled content met the required standards for physical properties and durability, demonstrating their suitability for use in packaging.

Stability and compatibility tests were conducted under extreme conditions, where the plastic containers were filled with pesticide products and stored at 40°C for 28 days. These tests validated that the containers with recycled content could effectively protect their contents under various logistical environments, ensuring product safety and maintaining packaging integrity. This comprehensive evaluation confirmed that using recycled material in plastic packaging is technically feasible and does not compromise quality or performance.

Table II. QC report of production trial with recycled material



DESCRIPTION	Existing Material	Trial Material (Regrind BASF)			NOTE
	100% virgin	50 : 50	60:40	70 : 30	
1 Dimension	OK	OK	OK	OK	
2 Appearance	OK	OK	OK	OK	
3 Colour	-	-	-	-	
4 Glossy	OK	OK	OK	OK	
5 Rigidity	OK	OK	OK	OK	
6 Odour	OK	OK	OK	OK	
7 Dropt Test	OK	OK	OK	OK	3 position x 1.2 m
8 Stacking Test	-	-	-	-	
9 Printing Test	-	-	-	-	
10 Leaking Test	OK	OK	OK	OK	15 minute (Lay down)
11 Top Load Test	17.8 Kg.f	15.3 Kg.f	15.7 Kg.f	16.7 Kg.f	Pressure 5 mm
12 Weight	18 gr	18 gr	18 gr	18 gr	

4.2 Economic Feasibility

4.2.1 Cost of cleaning process

The current washing process, utilizing dish soap, has proven effective in removing residues from plastic flakes due to the water-based nature of the products. An additional assessment on waste pesticide containers that underwent triple rinsing indicated no residual content. These findings support the proposal to reclassify these materials as non-hazardous, potentially reducing transportation costs by approximately 28%. The transportation cost comparison, shows the difference between hazardous and non-hazardous material transport costs, sourced from a company operating between Riau and West Java. The cleaning process involves several manual steps, including label removal, container splitting, shredding, washing with soap, rinsing, and drying. The proposed cost for the cleaning process is IDR 5,000 per kilogram of recycled material, with potential cost reductions through process automation and handling larger quantities of waste material.

4.2.2 Cost of waste material transport

The basic transport process employs a Wingbox truck with a loading capacity of 6,000 kg. The waste pesticide containers, cut into smaller pieces for efficient loading, are transported from Riau to a waste processing plant in Purwakarta, West Java. The transport cost per trip for hazardous materials is IDR 25,000,000, resulting in a cost of IDR 4,167 per kilogram. Reclassifying the materials as non-hazardous could significantly reduce these transportation costs, enhancing the economic feasibility of the recycling process.

4.3.3 Total cost of recycled material processing

The total cost for processing recycled material includes transport and cleaning expenses, amounting to IDR 9,167 per kilogram. This is compared to the cost of using virgin material for current packaging, which is IDR 47,200 per container. The cost analysis for production trials with different recycled material compositions (30%, 40%, 50%) reveals a decrease in the overall container cost as the recycled content increases. Despite the added cost of recycled materials, the total costs for jerry cans with recycled content demonstrate potential savings: -5% for 30% recycled content, 2% for 40%, and 8% for 50% (Table 3). This indicates that higher recycled content not only reduces the base cost but also contributes to significant overall savings, supporting both economic efficiency and environmental sustainability.

Table III. Cost saving comparison

Current packaging price (IDR)	**Jerry can price with recycled content (IDR)**		**Recycled material cost in the packaging (IDR)**	**Total cost of Jerry can with recycled material (IDR)**	**Cost saving (IDR)**	
47,000	30% recycle	45,936	3,300	49,236	**-2,236**	**-5%**
47,000	40% recycle	41,563	4,400	45,963	**1,037**	**2%**
47,000	50% recycle	37,620	5,500	43,120	**3,880**	**8%**

4.3 Regulatory Feasibility

4.3.1 Environmental assessment

The effectiveness of the triple rinsing process for pesticide containers has been well-documented, with studies showing that this method significantly reduces pesticide contamination to negligible levels, thus meeting safety standards. The study's results indicate that using 10 liters of water for triple rinsing effectively eliminates contamination. These contamination levels post-rinsing were virtually zero, indicating the thoroughness of the process. This method's effectiveness is also consistent with international practices, such as those implemented in Brazil's Campo Limpo program and other global initiatives. The adherence to these rinsing procedures significantly mitigates environmental risks, showcasing a robust framework for safe and sustainable pesticide container management.

4.3.2 Financial analysis

The financial feasibility of managing pesticide packagin waste involves analyzing various cost components, including the total volume and weight of waste generated, establishing collection points, and selecting efficient transportation modes. Factors such as the distance to recycling facilities, fuel consumption, labor costs, and equipment expenses are crucial. For instance, with a monthly generation of 10 tons of waste, five collection points, and an average distance of 100 kilometers to the recycling facility, the monthly transportation cost could include approximately $300 for fuel, $2000 for labor, $500 for equipment, and $300 for maintenance, totaling $3100.

4.3.3 Legal evaluation

The legal framework governing pesticide waste management emphasizes safety and environmental considerations. Regulations such as *Undang-Undang* No. 12 of 1992 and *Peraturan Pemerintah* No. 7 of 1973 outline the control and use of pesticides. Additionally, *Peraturan Menteri Pertanian* No. 24 of 2011 mandates certification for restricted pesticide use. The triple rinsing process, as recognized in these regulations, plays a critical role in decontaminating pesticide containers. Evaluating the effectiveness of this process involves measuring pesticide residue levels before and after cleaning to ensure compliance with safety standards. The reclassification of pesticide container waste based on post-cleansing contamination levels could potentially shift these materials from hazardous to non-hazardous categories, resulting in updated regulations and improved waste management practices.

4.4 Discussion

The effectiveness of the triple rinsing process in removing pesticide contamination from plastic containers has been demonstrated through various studies. Visual results showed that solutions not undergoing triple rinsing had a significantly higher contamination compared to those that did. Furthermore, the contamination values calculated in Table 4.2 confirmed that the triple rinsing process successfully eliminated contamination. This suggests that triple rinsing is sufficient to clear plastic containers from pesticide residues. Research by Karasali et al. (2014) supported these findings, showing a significant decrease in fenthion levels after triple rinsing. This process aligns with similar discoveries, such as those by Lwin (2023), who found that triple rinsing significantly reduces the likelihood of pesticide exposure and environmental contamination, promoting responsible pesticide use and compliance with regulatory standards (Karasali et al., 2014; Lwin, 2023).

The study identified significant cost savings when incorporating recycled materials into packaging. Using a composition with 50% recycled material resulted in a 13% cost reduction compared to packaging with 100% virgin material. Compositions with 40% recycled material yielded a 2% cost savings, whereas those with 30% recycled material increased costs by 9%, indicating that lower recycled content is not advisable. Sariatli (2017) found similar economic benefits in his research, highlighting substantial material cost savings in the European Union through the use of recycled materials. Implementing circular economy principles in production not only reduces material costs but also extends product lifecycles, enhances consumer satisfaction, and fosters stronger consumer-producer relationships through innovative reuse and recycling strategies (Sariatli, 2017).

The Focus Group Discussion (FGD) analysis emphasized the importance of proper pesticide waste management, Recommendations included banning non-recyclable containers, promoting triple-rinsing, implementing smart labeling and tracking, mandatory extended producer responsibility (EPR) schemes, incentives for container returns, spray services for small-scale farmers, and the use of refillable containers. Government Regulation No. 27 of 2020 on the Management of Specific Wastes provides a comprehensive framework for managing pesticide and insecticide waste, specifying collection and recycling methods for residential areas and agricultural waste management. These policies are crucial for ensuring effective and sustainable pesticide waste management practices, protecting both human health and the environment/

Several technical challenges must be addressed to optimize pesticide waste reduction through triple rinsing. Firstly, determining the optimal composition of recycled material is critical, as variations in performance were observed in different compositions. For instance, samples with 60% virgin and 40% recycled plastic showed inconsistent mass additions. The quality and composition of virgin and recycled plastics can significantly impact the effectiveness and safety of the final products, necessitating careful consideration of material properties. Secondly, ensuring the effective removal of pesticide residues is essential. Standard cleaning methods may not eliminate all pesticide traces, requiring advanced and potentially costly decontamination processes. The proposed recycling process, as outlined in Figure 3, involves thorough triple rinsing, proper sorting, and additional mechanical and chemical cleaning processes to ensure comprehensive decontamination. Implementing strict quality control measures and compliance with regulatory standards throughout the recycling process is vital to maintain the safety and performance of recycled products.

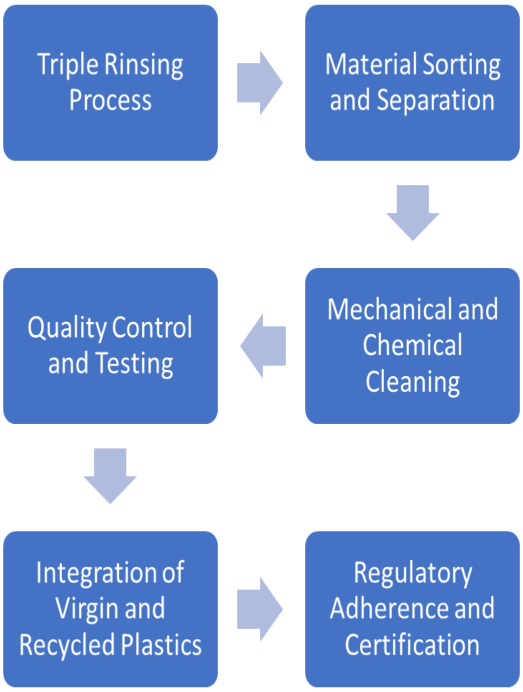


Figure 3. Propose Proper Recycling Process

CONCLUSION

The technical feasibility of recycling pesticide plastic packaging hinges on addressing challenges related to material composition and pesticide residue removal. New plastics generally offer more stable properties compared to recycled plastics, which may degrade with each cycle. Proper cleaning process at the waste processing plant plays an important role to ensure the effective removal of pesticide residues, safeguarding the quality and safety of recycled products while mitigating environmental risks. Economically, using a higher percentage of recycled material—ideally starting at 40%—proves cost-effective, enhancing market competitiveness by reducing raw material costs and potentially allocating savings to innovation and quality improvements.

The regulatory review recommends that the Indonesian government reclassify waste pesticide containers from hazardous to non-hazardous materials, based on the successful validation of the triple rinsing trial's effectiveness in removing pesticide residue. This reclassification, after the containers are triple rinsed, would reduce transportation costs from waste source locations such as plantations or farming areas to the waste processing plant, thereby enhancing the economic feasibility of recycling pesticide plastic containers.

To enhance the use of recycled materials, industries should conduct production trials with larger container sizes typical of pesticide applications, such as 20L containers. Adjusting the percentage of recycled material and potentially incorporating performance-enhancing chemicals will validate the technical feasibility of large-scale recycling. Additionally, industries must align with government regulations by establishing comprehensive compliance frameworks that adhere to best recycling practices, including triple rinsing and effective waste segregation. Strengthening Extended Producer Responsibility (EPR) schemes and advocating for their stringent enforcement will ensure producers remain accountable for end-of-life management of their products. Furthermore, investing in advanced recycling infrastructure, such as sophisticated sorting and processing facilities, will enhance the efficiency of recycling programs, facilitating regulatory compliance and promoting the sustainable reuse of materials.

REFERENCES

1. Sridharan, S., Kumar, M., Bolan, N. S., Singh, L., Kumar, S., Kumar, R., & You, S. (2021). Are microplastics destabilizing the global network of terrestrial and aquatic ecosystem services? Environmental Research, 198, 111243. https://doi.org/10.1016/j.envres.2021.111243
2. Thompson, L. A., & Darwish, W. S. (2019). Environmental chemical contaminants in food: Review of a global problem. Journal of Toxicology, 2019, 1–14. https://doi.org/10.1155/2019/2345283
3. Rajmohan, K. V. S., Ramya, C., Raja Viswanathan, M., & Varjani, S. (2019). Plastic pollutants: Effective waste management for pollution control and abatement. Current Opinion in Environmental Science & Health, 12, 72–84. https://doi.org/10.1016/j.coesh.2019.08.00
4. Dhananjayan, V., Jayakumar, S., & Ravichandran, B. (2019). Conventional methods of pesticide application in agricultural field and fate of the pesticides in the environment and human health. Controlled Release of Pesticides for Sustainable Agriculture, 1–39. https://doi.org/10.1007/978-3-030-23396-9_1
5. Koul, B., Yakoob, M., & Shah, M. P. (2021). Agricultural waste management strategies for environmental sustainability. Environmental Research, 206, 112285. https://doi.org/10.1016/j.envres.2021.112285
6. Shittu, O. S., Williams, I. D., & Shaw, P. J. (2020). Global e-waste management: Can WEEE make a difference? A review of e-waste trends, legislation, contemporary issues and future challenges. Waste Management, 120. https://doi.org/10.1016/j.wasman.2020.10.016
7. Lakhiar, I. A., Yan, H., Zhang, J., Wang, G., Deng, S., Bao, R., Zhang, C., Syed, T. N., Wang, B., Zhou, R., & Wang, X. (2024). Plastic pollution in agriculture as a threat to food security, the ecosystem, and the environment: An overview. Agronomy, 14(3), 548. https://doi.org/10.3390/agronomy14030548
8. Shah, F., & Wu, W. (2020). Use of plastic mulch in agriculture and strategies to mitigate the associated environmental concerns. Advances in Agronomy, 231–287. https://doi.org/10.1016/bs.agron.2020.06.005
9. Kibria, Md. G., Masuk, N. I., Safayet, R., Nguyen, H. Q., & Mourshed, M. (2023). Plastic waste: Challenges and opportunities to mitigate pollution and effective management. International Journal of Environmental Research, 17(1). https://doi.org/10.1007/s41742-023-00507-z
10. Chioatto, E., & Sospiro, P. (2022). Transition from waste management to circular economy: The european union roadmap. Environment, Development and Sustainability, 25. https://doi.org/10.1007/s10668-021-02050-3
11. Nasrollahi, M., Beynaghi, A., Mohamady, F. M., & Mozafari, M. (2020). Plastic packaging, recycling, and sustainable development. Encyclopedia of the UN Sustainable Development Goals, 544–551. https://doi.org/10.1007/978-3-319-95726-5_110

12. Picuno, C., Alassali, A., Sundermann, M., Godosi, Z., Picuno, P., & Kuchta, K. (2020). Decontamination and recycling of agrochemical plastic packaging waste. Journal of Hazardous Materials, 381, 120965. https://doi.org/10.1016/j.jhazmat.2019.120965
13. Hagelüken, C., & Goldmann, D. (2022). Recycling and circular economy—towards a closed loop for metals in emerging clean technologies. Mineral Economics, 35. https://doi.org/10.1007/s13563-022-00319-1
14. Li, H., A. Aguirre-Villegas, H., D. Allen, R., Bai, X., H. Benson, C., T. Beckham, G., L. Bradshaw, S., L. Brown, J., C. Brown, R., S. Cecon, V., B. Curley, J., W. Curtzwiler, G., Dong, S., Gaddameedi, S., E. García, J., Hermans, I., Soo Kim, M., Ma, J., O. Mark, L., & Mavrikakis, M. (2022). Expanding plastics recycling technologies: Chemical aspects, technology status and challenges. Green Chemistry, 24. https://doi.org/10.1039/D2GC02588D
15. Petruk, R., Petrushka, I., & Pohrebennyk, V. (2020). Environmental safety management of used packaging of pesticides and other dangerous substances. Environmental Problems, 5(1), 30–34. https://doi.org/10.23939/ep2020.01.030
16. Hossain, R., Islam, M. T., Shanker, R., Khan, D., Locock, K. E. S., Ghose, A., Schandl, H., Dhodapkar, R., & Sahajwalla, V. (2022). Plastic waste management in india: Challenges, opportunities, and roadmap for circular economy. Sustainability, 14(8), 4425. https://doi.org/10.3390/su14084425
17. Martin, E. J. P., Oliveira, D. S. B. L., Oliveira, L. S. B. L., & Bezerra, B. S. (2023). An Integrated Framework for Environmental and Social Life Cycle Assessments in PET Container Waste Management: A Case Study in Brazil. 1(3), 724–739. https://doi.org/10.3390/waste1030043
18. Picuno, C., Alassali, A., Sundermann, M., Godosi, Z., Picuno, P., & Kuchta, K. (2020). Decontamination and recycling of agrochemical plastic packaging waste. Journal of Hazardous Materials, 381, 120965. https://doi.org/10.1016/j.jhazmat.2019.120965
19. Briassoulis, D., Hiskakis, M., Babou, E., Antiohos, S. K., & Papadi, C. (2012). Experimental investigation of the quality characteristics of agricultural plastic wastes regarding their recycling and energy recovery potential. Waste Management, 32(6), 1075–1090. https://doi.org/10.1016/j.wasman.2012.01.018
20. Karasali, H., Kasiotis, K., & Anagnostopoulos, H. (2014). Experimental investigation of the efficiency of triple rinsing of agricultural containers regarding their characterization as non-hazardous wastes. Toxicological & Environmental Chemistry, 97, 1-10. https://doi.org/10.1080/02772248.2014.994519
21. Lwin, H. (2023). Comparative Analysis of Open Burning and Triple Rinsing Method for Empty Pesticide Container Management: A Review. OALib, 10, 1-10. https://doi.org/10.4236/oalib.1110380
22. Sariatli, F. (2017). Linear Economy Versus Circular Economy: A Comparative and Analyzer Study for Optimization of Economy for Sustainability. Visegrad Journal on Bioeconomy and Sustainable Development, 6. https://doi.org/10.1515/vjbsd-2017-0005

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