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Research article

A study of plastic waste management effectiveness in Indonesia industries

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Abstract: Waste management in Indonesia is less effective. According to Indonesia Statistics in 2016, the population in Indonesia reached 261,115,456 people and produced 65,200,000 tons of waste per year. Additionally, the growth of economy has an impact in industrial establishment. The activitity of industries lead to the increase of waste production. From the total waste piles, 85,000 tons per year are plastic waste. The waste pile will increase along with the projected increase in population and industrial growth. The considerable amount of plastic waste in Indonesia will be dangerous for the environment. Therefore, a strategy is needed to prevent the increasing amount of plastic waste in Indonesia. This study is conducted to determine the appropriate strategy to be done by identifying the type of plastic waste in Indonesia, mapping the flow of plastic distribution to become waste, and knowing the existing process of plastic waste management. A large number of plastic waste produce toxic substances swhich has to be handled properly. The root problem of the accumulation of plastic waste in Indonesia is the absence of an effective system in treating plastic waste. The result of this study is a solution that can be applied in order to reduce the accumulation of plastic waste in Indonesia by having industries across country to implement a sustainable system . Industries across Indonesia are expected to work together by creating and implementing a plastic waste management systems using a reverse logistics systems where plastic waste is returned to the factories that produce it. Afterwards, factories will manage the plastic waste by recycling and reusing them.

Keyword: Waste management strategy; plastics; sustainability; analytical hierarchial process

1. Introduction

The number of industries in Indonesia continue to increase over time [1]. The increase of industries will subsequently increase waste production. Therefore, it is necessary for the existing industries to implement a sustainable waste management system. Sustainable waste management system is related to the development of industrial processes that is carried out in a sustainable manner. It can provide various benefits such as reducing environmental pollution, increasing energy use efficiency, conserving resources to meet future needs, improving skills, creating safe working conditions, reducing production of waste that is hazardous to the environment, and implementing the use of materials that are safe and environmentally friendly [2]. This can minimize environmental pollution and increase industrial profit. One way that can be done in applying the principle of sustainability is by managing industrial waste.

Industries produce various types of waste [3]. It can be solid, liquid, or gas. Most of them had been processed before they are disposed. But there is one type of waste that is not treated properly i.e plastic waste that is often disposed directly without being processed [4]. This can disrupt the environment such as the marine ecosystem. The reasons why people dispose plastic waste directly are because the process to handle plastic waste is difficult and takes a lot of time . The use of plastics is also difficult to reduce because there is no material that can replace plastics in terms of characteristics and functions.

Most industries use plastic as a raw material for both packaging and additional materials in processing products [5]. The use of plastics in Asia has reached an average of 20 kg per year per person and it is expected to continue to increase. Comparing with other continents, Asia consumes around 30% of plastic in the world, which is followed by America, Europe and other continents. Every year, there are about 100 million tons of plastic used in various industrial sectors in the world [5]. The use of plastic will eventually become waste. Indonesia is ranked second as the most significant plastic waste contributor in the world [6]. The amount of plastic waste in Indonesia reaches 14% of the total number of daily piles, equivalent to 85,000 tons per year. 3.2 million tons of plastic wastes are dumped into the sea [7]. According to the World Economic Forum (2018) [8], 16% of plastic waste was recycled, but only 2% of plastic waste can be recycled effectively. In addition, 14% of the plastic waste was burned, 4% was buried in End Disposal Site (EDS)/Temporary Disposal Site (TDS), and 32% polluted the environment and disturbed the ecosystem. Considering the current plastic management system, it will become a massive problem. Recycling plastic waste naturally will take up to 600 years [9].

To deal with problems discussed above, a strategy is needed to prevent the increasing amount of plastic waste. The contribution of industries in processing waste will be very helpful in maintaining environmental stability and environmental health in Indonesia. If an industry implements a good plastic waste management system, the industry has implemented a sustainable system to reduce plastic waste piles. Managing plastic waste is not easy and expensive [5]. Only a small amount of plastic waste treatment is truly effective which is why contributions from industries across Indonesia are needed to help managing plastic waste as well as possible. The objective of this study is to analyze the problem of plastic waste in Indonesia as well as providing a solution to counteract it.

Various methods has been used to deal with the issue of plastic waste such as the implementation of 4R (Reduce, Reuse, Recycle, as well Refusing), but there are complications that comes with each method. The study found that recycling is the most effective method to combat the problem of plastic waste in Indonesia and suggested an implementation of reverse logistics system. The reverse logistics system allows the plastic that has been used by consumer is returned to the factory that produces it so that it can be recycled. Therefore, establishing a sustainable waste management system is the most favorable concept to reduce plastic waste.

2. Methodology

2.1. Flow chart

The methodology is started by finding the problem first. Searching for the problem is conducted by observing the symptoms that are seen in the environment. After general issues to be discussed is known, literature studies are conducted through various media such as books, papers, and internet to increase the knowledge of researchers in passing on the problems. Next, the researcher collected secondary data from various sources such as waste treatment data that has been carried out in Indonesia, the amount of plastic waste in Indonesia, the flow of plastic waste in Indonesia, and so on through the internet. The data is processed to obtain the appropriate results. Data processing is conducted by mapping the flow of plastic waste processes using the rich picture. The rich picture can provide an understanding of the flow of processes that occur along with the stakeholders involved. After getting the general view, the researcher is then searching for the root cause using fishbone diagrams. After finding out the root cause, several alternatives can be developed to solve the problem based on the root cause. These alternatives will be assessed using the Analytical Hierarchical Process (AHP) method. AHP will provide the process that is considered the most appropriate to be applied to solve these problems. Furthermore, the analysis and interpretation results of data processing are conducted. The results of the analysis are the solution offered to solve the problem.

2.2. Sustainability in industry

Sustainability is the process of maintaining balanced changes [10]. This change can be defined as a socio-ecological process carried out continuously. The aim is to increase current economic growth without using resources for future generations [12]. The sustainable system is implemented by industries to minimize the negative impacts of waste and maintain environmental sustainability for a long time. The balance of the sustainability system consists of 3 main dimensions: economic, social, and environment. The three aspects are interrelated and influence each other [11].

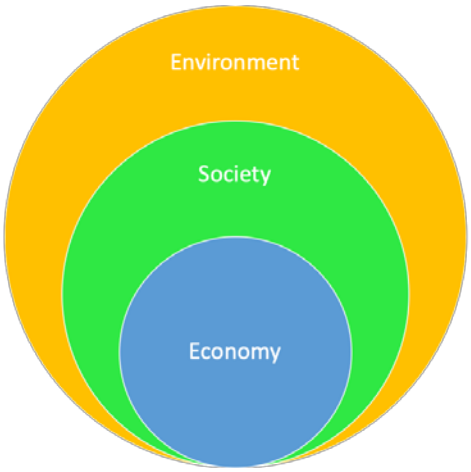

Figure 1. Three main dimentions of sustainability system [11].

Figure 1 shows the interrelation between economy, society, and environment. Economic and energy growth in the future will affect environmental balance [12]. Therefore sustainability should be implemented to prevent pollution, conserve natural resources, and protect the remaining environment. Sustainability in the industry is expected to be carried out in the long term that can respect the environment, improve the welfare of employees, increase profitability, and increase profits and market share of the industry itself [2]. The increase of implementation of green technology which produce less pollution will help these industries to implement more sustainable systems.

Implementation of sustainability in the industry requires the industry to understand how to respond to environmental, economic and social conditions. Implementing sustainability system will be a challenge since it will affect the culture of the industry.

The implementation of sustainable system will provide some benefits to the industry. These benefits includes reducing energy use to reduce production costs and increase the efficiency of the industrial processes. The increase of efficiency will reduce waste as well as pollution. In addition, the implementation of the sustainability system will provide an opportunity for existing industries to get new market segments so it can increase sales, revenue, and competitive advantage.

2.3. Plastics

Plastics are synthetic or semi-centric polymerization products formed from organic condensation or the addition of polymers [13]. Plastic has a lower degree of crystallinity than fibre. Plastics can be softened or printed at high temperatures using a variety process such as injection moulding or extrusion. Plastics are waterproof, lightweight, easy to form, and flexible. They can be used as packaging for a variety of object such as products, storage areas, additional materials for automotive. There are various types of plastic used in packaging as shown in Figure 2 [14].

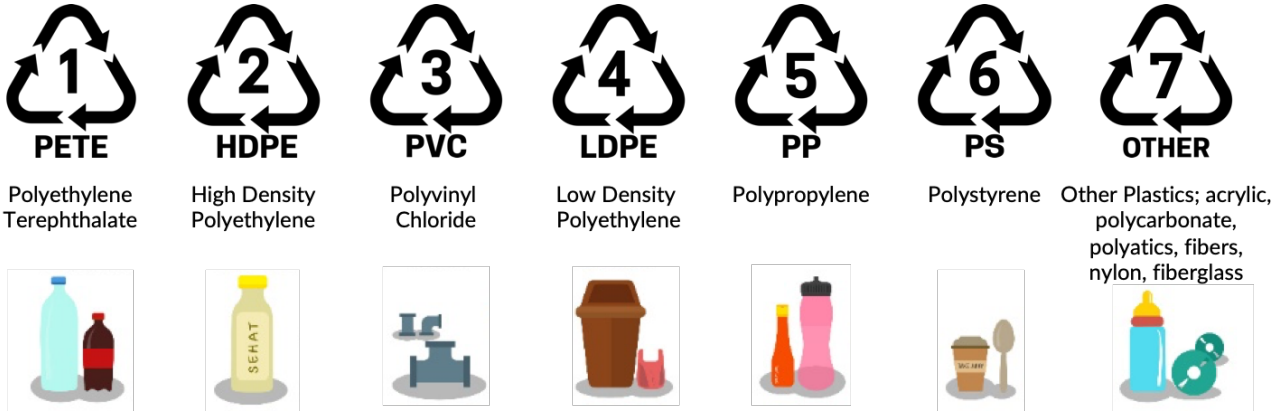

Figure 2. Type of plastic [13].

1) Polyethylene Terephthalate (PET) is a type of plastic that is lightweight and durable. This type of plastic mostly used as bottled water, soda bottles, juice, cooking oil, and food packaging. This bottle is single use and it should not be cointained hot water.
2) High Density Polyethylene (HDPE) is a strong and rigid type of plastic. Usually used as shampoo bottles, liquid soap bottles, and shopping bags,. This type of plastic is not reuseable.
3) Polyvinyl Chloride (PVC) is a type of hard plastic and used as an electrical cable, glass cleaning bottles, and water pipe. PVC is not recommended to be used as a food or beverage packaging because the substances contained in PVC can disrupt the digestive system.
4) Low Density Polyethylene (LDPE) is a type of plastic that is easily formed in high temperature, hard and strong. This type of plastic mostly used as bags, bottles, storage boxes, and toys. This type of plastic is very safe to use for food or beverage packaging. However, LDPE is difficult to destroy but can be recycled into household furniture and trash cans
5) Polypropylene (PP) is a type of plastic that is easily formed in high temperature, flexible, hard, and resistant to fat. Because of the nature of this plastic, it is used as food containers, plant pots, drug bottle caps, and straws
6) Polystyrene (PS) is a type of plastic that is easily formed in high temperatures and is very stiff at room temperature. Polystyrene can be found in plastic tools, CS boxes, and plastic cups. This plastic is the primary material for styrofoam. This type of plastic is unfavourable to use because it can be used once, can not decompose by the soil, and can release toxic gas when burned.
7) Other types of plastic produced with label seven are made from a mixture of two or more types of plastic which indicate that the resin is unknown. This type of plastic is used in the food or beverage industry.

2.4. Flow of plastic distribution

The distribution process is the process of delivering goods from producers to consumers [15]. The party conducting the process is referred to as a distributor, as shown in Figure 3.

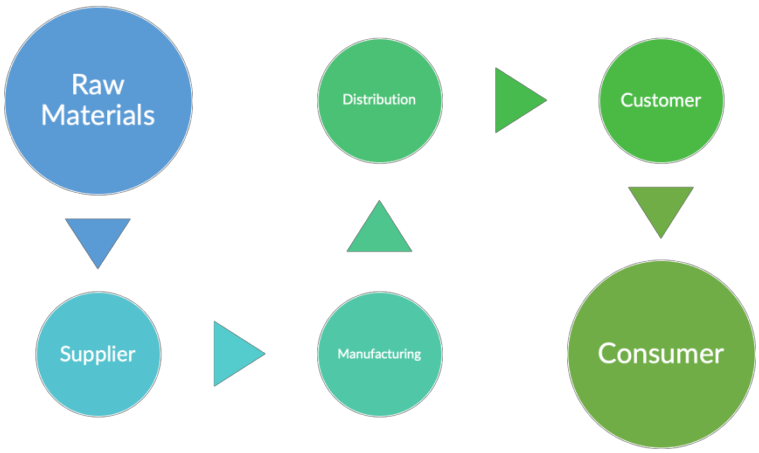

Figure 3. Distribution process [16].

The distribution process is carried out in various ways [17]. Direct distribution is where the distribution of goods from producer are sent directly to consumers without using a distribution channel. Another method is indirect distribution. This method is where the distribution of goods from the producer are not directly sent to consumers but through the distributor such as agents and retailers. Last method is semi-direct distribution. This approach means the distribution of goods is carried out using distribution channels but the distribution channel is a part of the producer.

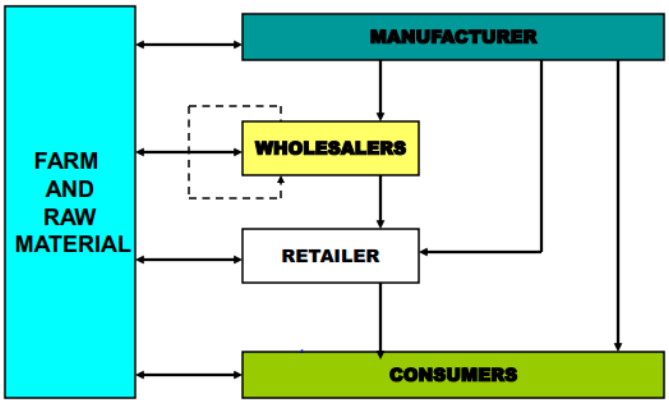

Figure 4. Distribution flow [18].

Plastic is distributed from the industry to consumers through wholesalers and retailers as shown in Figure 4 [19]. But there are also industries that produce plastic itself to be used as packaging for their products. Then the product will be distributed to consumers. After consumers use the product, the packaging of the product will become a waste. In addition, the industry will also produce industrial waste and makes additional plastic waste in Indonesia.

The raw material for making plastic is petroleum and other components [20]. The raw material is collected by suppliers. Then the supplier processes the raw materials until they are ready to be used. The supplier then provides to not only plastics industry but also other industries that use plastic as raw materials for their products such as the household products industry, and plastic pipe industry.

The plastic industry then distributes its products to various parties such as supermarkets, consumers, and other industries that use plastic as packaging. But there are also industries that process their own plastic to be used as packaging for their products. The product then will be distributed to sellers and consumers. After consumers use the product, the product will be disposed. The waste will be collected by plastic waste collectors and given to the plastic recycling industry or collected in the Waste Disposal Site. Then, the plastic can be processed and recycled.

Based on the process of plastic production from upstream to downstream, the whole system consists of several interrelated subsystems, there are (1) Primary raw material subsystem which is preparing primary raw materials from petroleum. (2) Production process subsystem which is making and processing plastics. (3) Plastic waste management subsystem which is collecting and transporting plastic waste and the final disposal process. (4) Plastic recycling subsystem which is collecting plastic waste that can be recycled by plastic waste collectors, sorting of plastic types, plastic milling, plastic washing, and drying of plastic debris which is then will be send to plastic factories as secondary raw materials.

The current research shows that some new methods are applied to estimate the origin of plastic waste to optimise collection and transportation. The study from Blanco (2018) [21] succeeds to define collection centre by determining the high densities plastic in the agricultural area. GIS technology is applied in this research to map the region with the highest plastic density. Furthermore, the result can become the basis to plan the operational strategy to transport the waste because the data from GIS can be updated.

2.6. Reverse logistics

Reverse logistics is the process of planning, implementing, and controlling the flow of raw materials, work in process, finished goods, and related information, which is flowed from the point of consumption to the point of origin efficiently [22]. Logistics generally bring products to customers. Reverse logistics is the opposite of the process where the product or goods are brought from the customer to the distributor or to the manufacturer which includes reprocessing or disposal [23]. The transfer of the product or item is carried out through a supply chain network.

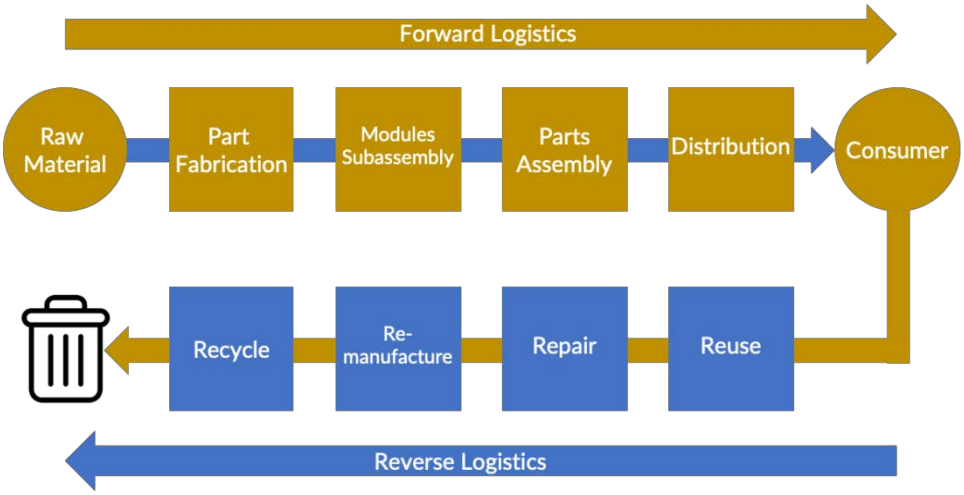

Figure 5. Reverse logistics [24].

Reverse logistics (as depicted in Figure 5) system can increase industrial competitive advantage and improve the industrial economy. Industries that implement reverse logistics systems can reduce the impact of environmental pollution by reducing the waste produced and increasing social responsibility. Another advantage from the use of reverse logistics are cost reduction, faster service, customer retention, and reducing losses and benefits that are not planned [25].

2.7. Plastic waste management

Waste treatment process is based on the physical properties of the plastic. The physical properties of plastics are divided into 2 types [26]. Thermoplastic is a type of plastic that can be recycled by reheating process. Plastics that are classified into thermoplastics include polyethylene (PE), polystyrene (PS), ABS, and polycarbonate (PC). Another property is thermoset. This type of plastic that cannot be recycled or reprinted because the molecules in the plastic will be damaged if reheated. Plastics that are classified into thermosets include epoxy resin, bakelite, melamine resin, and urea-formaldehyde.

Furthermore, plastic reduction waste can be done in 4 ways which are reduction in use, destruction by landfilling/incineration, recycle and reuse. Reduction in use means a reduction in the use of plastic by substituting the use of plastic with other materials. Destruction is the process of damaging plastic structure that can be done by landfilling or incineration. Landfilling is a process where plastic waste will be buried in the ground [27]. Incineration is the process of burning plastic waste at high temperature. Recycle is a process where plastic waste will be processed to be used again. Reuse is a process of reusing plastic that has been used before. This can be done using plastic products that can be used repeatedly like refillable plastic bottles.

In terms of plastic waste, recycling process for solid plastic waste types is generally done in three ways [28]. First method is mechanical recycling. This process contains of separating, sorting, baling, wasing, grinding, compounding, and palletizing [29]. Recycling using this process can be configured using closed and open loops where the application will provide a different final version of the recycled product. The closed loop process will produce products that have properties similar to the original material so they can be used as raw materials with high added value. The process carried out by a method of extrusion. The open loop process will produce products that have more labor properties than the original material so they are only suitable for specific applications such as garbage bags andpipelines. This process is carried out through the stages of cutting, washing, drying and re-granulating.

Second method is chemical recycling. The proceess of breaking the polymer structure [29]. The aim is to get genuine monomers or other valuable chemicals. Chemical recycling can be done by chemolysis, pyrolysis, fluid catalytic cracking (FCC), hydrogen technologies, Katalytische Drucklose Verölung or Catalytic Pressure-less Depolymerization (KDV) process, and gasification combined with methanol production. The last approach is energy recovery. Energy recovery is carried out by burning plastic waste aimed at electricity production and district heating with efficiency above 90% [28]. This process is usually done for plastic waste that cannot be recycled.

3. Data collection

3.1. Plastic waste data in Indonesia

The amount of plastic production in Indonesia changes every year and is uncertain. Based on statistical data [1], plastic production in Indonesia reached the highest number in 2012 where plastic production almost touched 10.2 million tons (see Figure 6). In addition, Indonesia's capacity for plastic consumption is increasing every year (see Figure 7). Figure 7 shows that plastic consumption is used in various sectors such as electronics, buildings, automotive, and packaging. According to Figure 8, types of plastics used as packaging come from PE (28%) and PP (19%).

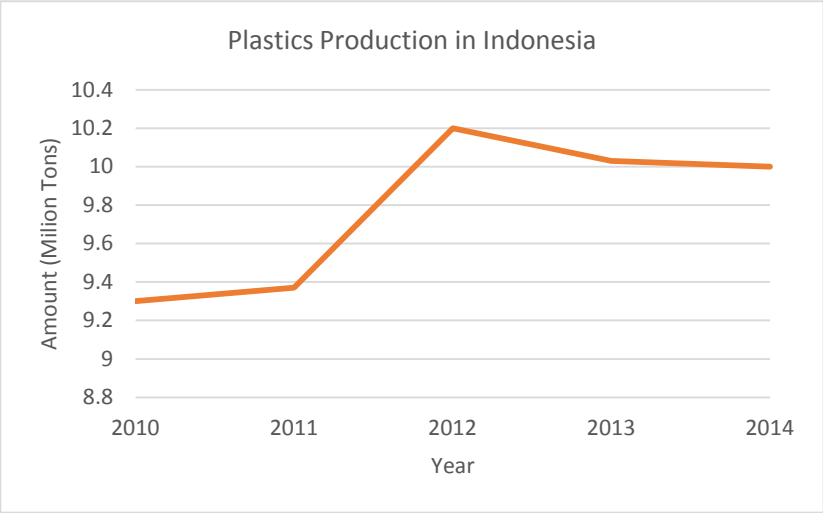

Figure 6. Plastics production in Indonesia [1].

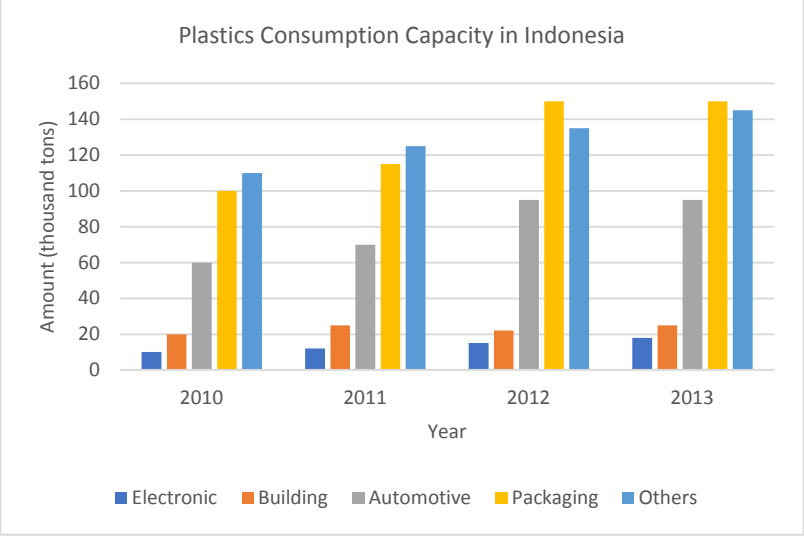

Figure 7. Plastic consumption capacity in Indonesia [1].

Figure 8. Type of plastic packaging used in Indonesia [1].

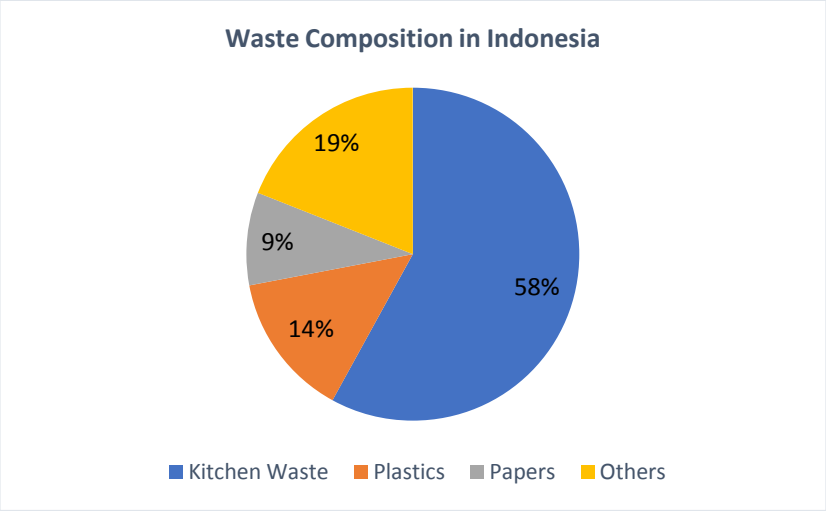

Figure 9. Waste composition in Indonesia [1].

Based on Figure 9, the amount of plastic consumption and the amount of plastic waste produced in Indonesia are high. Plastic waste production in Indonesia reaches 14% of the total daily stockpile or equivalent to 85,000 tons per year. 3.2 million tons of plastic waste are just dumped into the sea. According to the World Economic Forum [8], 16% of plastic waste is recycled, but only 2% of plastic waste can be recycled effectively. In addition, 14% of the plastic waste was burned, 4% buried in End Disposal Site (EDS)/Temporary Disposal Site (TDS), and 32% polluted the environment and disturbed the ecosystem. Various types of waste gives different toxicity. Based on various researches as depicted in Figure 10, the most toxic type of plastic waste is PVC, followed by PET.

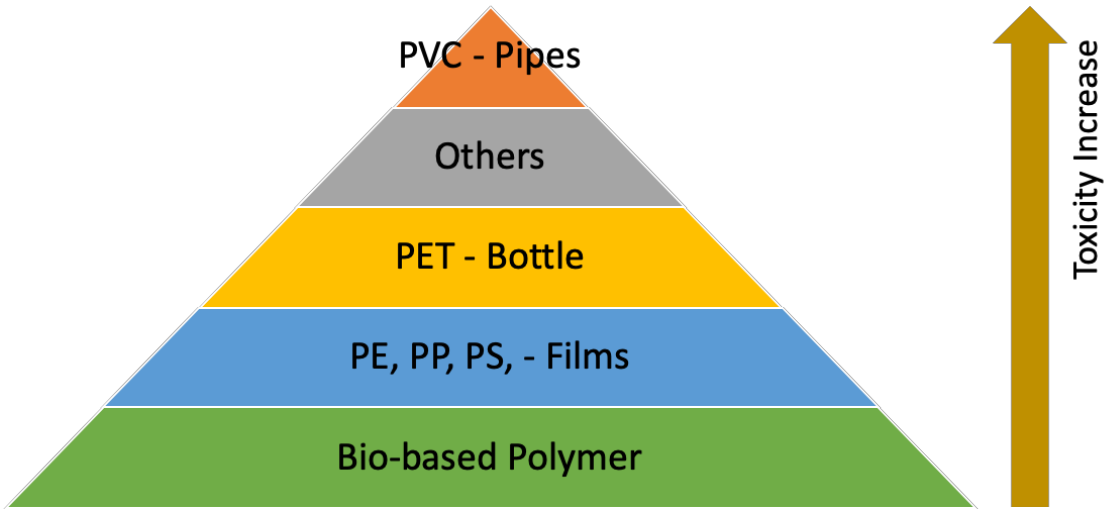

Figure 10. Toxicity of plastic [20]

3.2. Plastic waste processing data in Indonesi

Indonesia has also implemented the 4R system to reduce plastic waste. The 4R is done by: Reduce, refuse, recycle, and reuse. Reducing the use of plastic has been applied in several industries in Indonesia by replacing the packaging material using other alternative ingredients. In addition, the government has also applied a system of having the customer paid for plastic bags to reduce plastic consumption in Indonesia. Refusing process by using incinerator. This method is widely used after landfilling waste is decreasing. Landfilling process has not been used as the main process in reducing plastic waste. Another process is recycling. The recycling process in Indonesia has been carried out in various ways, such as processing waste into asphalt mixture and using plastic as raw material in making handicrafts. The reuse process carried out in Indonesia is the reuse of plastic products such as plastic bags, and gallons.

Indonesia, the processing of plastic waste is divided into three main processes; collection, transportation, and disposal. First process is collection. This process allows all plastic waste compile from various places such as houses, offices, and industries. Transferring processes is sending the collection of garbage to disposal facility by using truck/trailer. The last process is disposing garbage in landfill

Plastic processing is commonly done in the form of plastic packaging, plastic melting, and plastic printing. Recyclers in Indonesia mostly only sort and wash plastic waste. It is very rare for recyclers to melt the plastic into plastic seeds. Milling or crafting is intended to process plastic waste into secondary raw materials for plastic factories. Indonesia has also been processing plastic used as a mixture of asphalt [4]. Industries in Indonesia also contribute to reducing the existing plastic waste by optimizing the plastic wrap used in the final product. As a result, there was a decrease in plastic usage by 13%. In addition, Indonesian people have used plastic materials to make art and handicrafts. This handicraft creation will improve the economy of the community and also reduce the existing plastic waste.

4. Results and interpretation

Plastic waste in Indonesia comes from various sources [30]. The waste will then be distributed to a dumping place for further processing. The sources and processing of these wastes are interconnected with one another and form several sub-systems in a large system. These sub-systems will affect each other to form a process that runs from upstream to downstream. The journey of the process and related parties is illustrated in Figure 11.

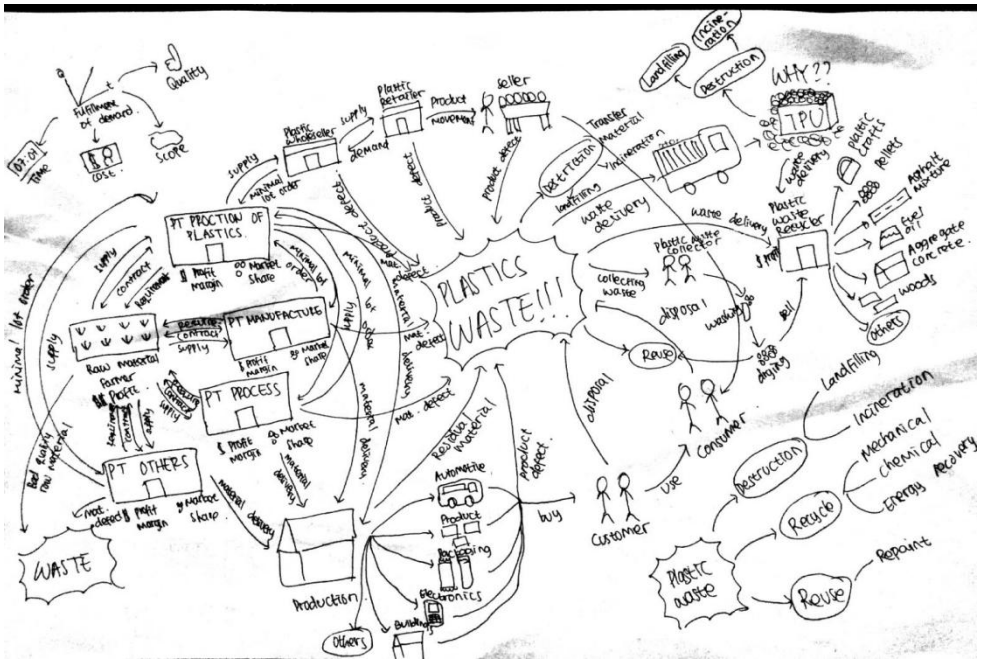

Figure 11. Rich picture of plastic waste system.

In this case, the process will produce plastic waste from consumers and industries, both manufacturing industries and process industries. Plastics are generally used as raw materials for production processes because plastic has various benefits at a reasonably cheap cost. In addition, the nature of plastic that can hold water and moisture are very preferred to be used as packaging so the reduction in the use of plastic is quite difficult.

Based on the data obtained, the plastic recycling industry cannot be relied upon to manage all plastic waste in Indonesia. Other industries that use plastic as packaging or as raw material to produce their products should contribute to managing plastic waste in Indonesia. Only a few industries in Indonesia have implemented sustainable waste management system because the assumption of the industry itself is that the application of waste management is expensive. The machines used to treat plastic waste are expensive. Industry is the biggest contributor to the use of plastic in Indonesia and the application of plastic sustainable waste management system can provide more value to industries. In addition, problems that often occur in Indonesia can be seen from the symptom that arise in everyday life is the accumulation of plastic waste in the dump. This indicates that the use of plastic in Indonesia is very large and increasing. The fishbone diagram method is used to find out the root cause of these symptom as shown in Figure 12. After finding the root cause, it

was found that the amount of plastic waste pile in Indonesia was caused by the absence of effective methods for manage the plastic waste.

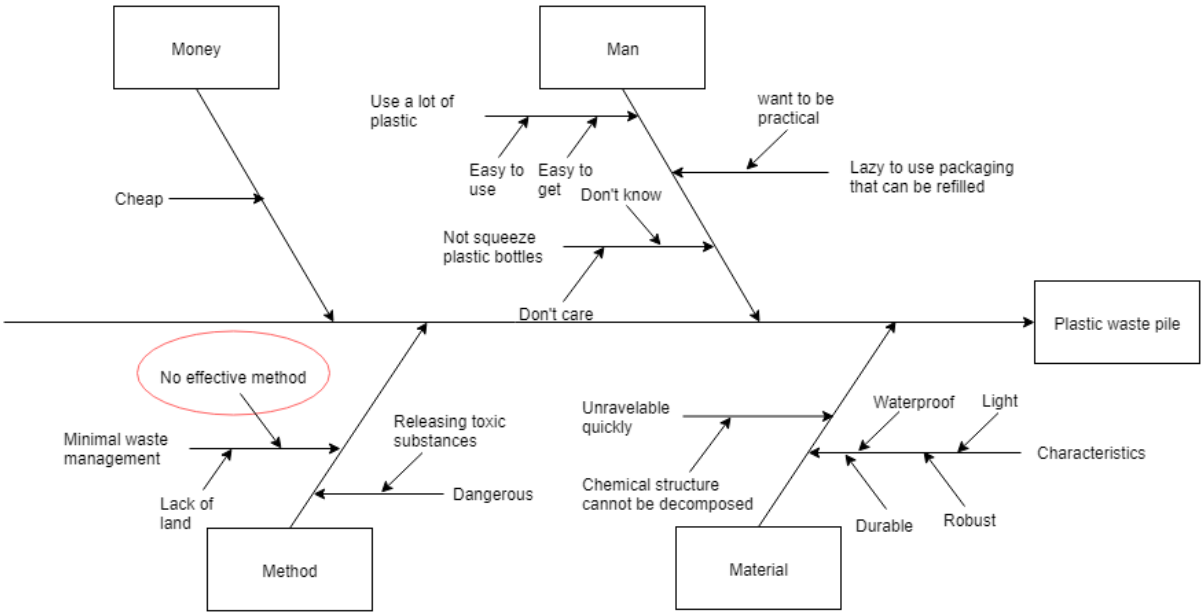

Figure 12. Fishbone diagram.

The root cause of the problem is the absence of an effective method for managing plastic waste. The equipment used to conduct plastic waste management is available with effective technology but has not been utilized as well as it could be. Solution development can be done based on consideration of several factors [31], there are:

1. Technological factors

The development of plastic processing machinery is growing over time. As time goes on, technology will become more sophisticated to the point where it can process plastic waste optimally. Few industries in Indonesia apply plastic waste management systems because the technology needed is expensive. The use of technology will be an important factor in determining the application of a plastic waste management system.

2. Environmental factors

The application of plastic waste management processes has an impact to the environment. One of the impacts is the smoke from burned plastic waste. The management of the waste is intended to reduce the impacts on the environment. Therefore, environmental factors become one of the considerations in determining the application of a plastic waste management system.

3. Regulatory factors

Regulations stipulated by the government such as legislation related to policies in managing waste will be a limitation in implementing plastic waste management system. Regulations regarding the obligation to apply the plastic waste recycling process can support industries in implementing sustainable plastic waste management systems. The regulation related to the scope of waste management, community participation, and other regulations as stated in UU RI No. 18 About Waste Management needs to be considered before implementing a plastic waste management system [32].

4. Economic factors

The price of waste processing machines will be one of the industry's concerns in terms of the economy. But on the other hand, the application of plastic waste recycling processes can improve the industriy's economy indirectly. Not only for the industry, the application of plastic waste management can also improve the economy for scavengers and recyclers. Industry can get additional income through sales of processed plastic waste products. Likewise scavengers and recyclers can increase their income by participate in the implementation of a sustainable waste management system. Therefore, this can be a consideration for industry in implementing a plastic waste management system.

5. Social factors

Community participation influences the process of plastic waste management in Indonesia. Public awareness in collecting plastic waste will be a success factor for the application of plastic waste management. For this reason, it is necessary to pay attention to the behavior of the community towards plastic waste to find out what process is feasible to be applied in carrying out the processing of plastic waste on an ongoing basis considering the industry that implements the system requires contributions from various parties including the community.

When reviewing the plastic waste management system in Thailand, the success of the management of plastic waste comes from its efforts in developing networks and activities between various related parties [30]. The alliance is carried out in the form of bank waste formation in schools or villages so that waste can be delivered immediately. Next, donors were given to the pastor in the temple to collect and sorted plastic waste. Then the waste market is carried out where the local community will bring waste that has been separated to the shocked market and they will be paid at a predetermined price. Reviewing this, it does not rule out the possibility that Indonesia can effectively manage plastic waste. Processing carried out in this case can be seen in the form of 4R which has been applied in Indonesia. But there are several problems that arise in processing plastic waste:

1. It is difficult to sort plastic waste because most of the Indonesian people dispose of garbage by mixing all the available waste so that it is difficult to separate plastic waste and other waste.
2. Difficulty in melting plastic because the plastic used is mixed material (reduced purity).
3. The number of types of plastics that are multilayer which makes plastic processing more difficult because of the complicated separation process.

Based on the waste management that has been done in Indonesia, the easiest process to do is destruction by incineration process. The equipment needed is not too expensive and plastic waste can be significantly reduced. But this process has negative impacts resulting from the incineration process because not all types of plastic are safe to burn. Based on the literature study conducted, incineration of PVC will pollute the air because PVC-type plastic will emit halogen gas which is a toxic gas when burned [33]. In addition, burning plastic can cause a risk of adverse health effects, especially the risk of breathing. The remainder of the plastic incineration in the form of air particulate emissions (soot) and solid residual ash (black) will have a negative impact on health and the environment. Similarly, the incomplete incineration of PE, PP and PS plastics can cause pollution such as smoke and ocarbon monoxide. The solution that can be done is by reducing and replacing the use of this type of plastic with polyethylene because it is more easy to degrade when compared to polypropylene. The incineration process should also be reduced and substituted with the pyrolysis process because the pyrolysis process can produce fewer toxic substances.

The implementation of destruction by landfilling in Indonesia has becoming difficult to do because the available land to be used is decreasing considering the increasing population of Indonesia. This process is easy to implement and can reduce plastic waste significantly but there are many negative impacts [34]. One negative impact that arises is the release of dangerous chemical compounds from the plastic and which will be absorbed into the soil. It will cause water pollution in the soil. When the water evaporates, various minerals and organic substances will be carried in the form of an inseparable suspension. The presence of a decomposed hazardous substance from the plastic waste will cause pollution. Therefore the application of landfill needs to consider the geological location and structure. This is not easy because the available land in Indonesia has begun to decrease, making it difficult to obtain suitable land for plastic landfill.

The implementation of plastic use reductionin Indonesia is very possible. But for now, there is no material that can replace plastic in terms of characteristics and prices. There are many materials that has the same characteristics as plastic. In fact there are quite a lot of materials that have better quality when compared to plastic. But these materials are more expensive. This has led to the reluctance of various industries to replace their raw materials because it will increase the production cost and reduce profit margins. The lower profit margin can be caused by the increasing Cost of Goods Sold (COGS) but a fixed selling price. Which is why material that can replace plastic at a lower price is needed. Likewise, this is also why the implementation of reuse in Indonesia is needed. Communities in Indonesia have implemented reuse process. However, the application of this process is less effective because it cannot reduce the plastic waste significantly.Several types of plastic can be reused but within a certain time limit, but in the end, it will also become a waste.

Another application that has been implemented in Indonesia is recycle. Recycle can be done in various ways and provide more benefits. This process does not require large land such as the destruction process and can reduce plastic waste significantly. However, the application of recycle often requires high operational costs because the machinery needed to process waste is expensive. Not all types of waste can be processed using the same machine. The application of this process also produces negative impacts on the environment, such as contributing to global warming because the machinery used to melt plastic will produce harmful emissions gases and greenhouse gases.

To determine which process is the most feasible to implement in reducing plastic waste in Indonesia, the researcher conducted a weighting using the AHP matrix. The weighting calculation is based on predetermined criteria. Determination of these criteria is conducted using brainstroming method. Then the results of the brainstorming were chosen based on the researchers' judgment and there are four criteria: Ease of implementation, effectiveness, operational costs, and Negative impacts produced

The four criteria are compared and weighted to find out which criteria is the most important. Weight calculation is conducted by using pairwise comparison matrix with 9 scales where scale 1 means equal importance and scale 9 means extremely more important as shown in Table 1.

Table 1. Fundamental scale.

Fundamental Scale (Row vs Column)	
Extremely Less Important	1/9
	1/8
Very Strongly Less Important	1/7
	1/6
Strongly Less Important	1/5
	1/4
Moderately Less Important	1/3
	1/2
Equal Important	1
	2
Moderately More Important	3
	4
Strongly More Important	5
	6
Very Strongly More Important	7
	8
Extremely More Important	9

The scale set for each comparison is based on the judgment of the researcher. Based on the weight calculation performed, it was found that the resulting consistency value was 8.4% with the highest priority criteria is effectiveness with a weight of 0.479. The results of the Calculation of priority vector of criteria is shown in Table 2.

Table 2. Priority vector of criteria.

Criteria	
Ease of Implementation	0.05
Effectiveness	0.48
Operational Cost	0.18
Negative Impact	0.29

The calculation of priority weights for each alternative is carried out on each criterion to find out the alternatives that are considered most important on each criterion. The calculation of priority of each alternative is conducted by using pairwise comparison matrix with 9 scales where scale 1 means equal importance and scale 9 means extremely more important. The scale set for each comparison was carried out as in the calculation of priority vector of criteria which is based on the judgment of the researcher. The results of the priority vector of each alternatives calculation is shown in Table 3.

Table 3. Priority vector of each alternatives.

Priority Vector		Criteria			
		Ease of Implementation	Efectiveness	Operational Cost	Negative Impact
Alternative	Reduce	0.03	0.04	0.15	0.48
	Landfill	0.08	0.42	0.04	0.03
	Incineration	0.22	0.19	0.14	0.09
	Recycle	0.24	0.31	0.11	0.16
	Reuse	0.43	0.03	0.55	0.23

Furthermore, overall priority calculation is performed to find out the best alternatives by considering all criteria. The overall priority calculation is done by multiplying priority vector of criteria with priority vector of each alternatives. Each criterion weight will be multiplied by the criteria value in each alternative, then the value of the multiplication of all the criteria is summed for each alternative and it was found that the best alternative is recycle with a value of 0.23. The overall priority calculation results are shown in Table 4.

Table 4. overall priority.

	Overall Priority
Reduce	0.19
Landfill	0.22
Incineration	0.16
Recycle	0.23
Reuse	0.20
Total	1.00

Based on what have been explained previously, the most feasible plastic waste reduction process to be implemented in Indonesia is recycle. In implementing recycle, industries in Indonesia are expected to work together by creating and implementing a sustainable plastic waste management system. The process of collecting plastic waste can be carried out in various ways. For example, through the implementation of a reverse logistics system where the plastic waste is returned to the industry that produces it. In this case, it is necessary to disseminate information to the public and other stakeholders so that the system can run well. The socialization can be carried out in the form of a lure given to the community to be willing to collect the waste and return it to the industry. The distribution channel can be through the seller or directly to the relevant industry. Another process that can be done in collecting plastic waste is the application of network development systems such as those carried out in Thailand where waste disposal sites are made near in several places. Then the purchase of sorted waste is made so that it will facilitate the industry in processing the collected plastic waste.

Every industry uses a variety types of plastic. If an industry is required to process all the plastic waste it produces, the industry will not be willing to implement a sustainable waste management system because the machines needed to process various types of plastic are different and expensive. Therefore there is a solution in which industries in Indonesia can work together in implementing a

sustainable plastic waste management system by applying specific process of plastic waste management for each industry. For example, industry A processes PET and HDPE plastic types, industry B processes PVC and PET plastic types, while industry C processes PET, HDPE and PVC plastic types. The system will make it easier for industries to implement sustainable plastic waste management systems. All PET types from various industries will be distributed to industry A to be processed as well as other industries. Processing results from each industry can be sold or distributed to various industries as raw material for making products according to industrial needs or can be used as raw material for products from the industry itself.

Specific applications of plastic waste management that can be applied by industries are:

1. Processing plastic waste into asphalt mixture
   Plastic waste can be treated as a basic material used for an asphalt mixture. Additional plastic materials will strengthen the stickiness of the asphalt. Steps that can be taken are; Plastic waste cleaning process, Shredding, transforming the waste based its size, Waste plastics mixed with the hot aggregate, and Aggregating plastics-bitumen mix
2. Processing plastic waste into pellets (plastic seeds)
   Plastic waste can be recycled and used as an ingredient for plastic bags [35]. Waste that can be used in this process is thermoplastic. Plastic waste treatment is carried out through the following steps. First, Enumeration to transform the plastic into flakes so that it can be carried out by using a shredding machine, then wash the plastic to remove dirt and bacteria that can interfere the production process. The next phase is drying to minimize water that can interfere the production process. Finally, making pellets is done by melting the plastic chopped using an extruder, then formed into a long cylindrical rod and cooled until becomes solid. To get pellets in satisfying size, the cylinder rod should be cut.
3. Processing plastic waste into fuel oil
   Plastic waste can be recycled and processed into fuel oil through a pyrolysis process [36]. The catalysts are derived from Residual Fluid Catalytic Cracking (RFCC) waste in the depolimarasation process. The most oil that can be acquired is from the type of PS plastic which is then followed by PP, LDPE, HDPE, and PVC plastics.
4. Recycling PET bottle waste as fiber in recycled aggregate concrete
   The use of Recycled PET (RPET) on recycled plastic fiber for reinforcing Recycled Aggregate Concrete (RAC) will significantly increase strength [37]. The steps taken include are; collecting PET plastic waste, washing the plastic, cutting PET plastic waste, rinsing and drying of PET plastic waste, and mixing the fibre with concrete
5. LDPE processing becomes a mixture of wood
   This processing is carried out by mixing LDPE plastic melt with sawdust with a ratio between the polystyrene weight and sawdust of 1: 1.5 [38]. Then, the product is cooled to a temperature between 170 and 180℃.This mixing produces a durable strength and can be used for furniture, carpentry, and building.

The implementation of the system is expected to be able to reduce plastic waste piles in Indonesia and help various parties in improving their economy.

5. Conclusion

Plastic waste management activities in Indonesia have not been effective in their goal due to the lack of industry contributions in implementing sustainable systems. The implementation of a sustainable system is expected to help reducing the amount of plastic waste in Indonesia effectively. Indonesia produces about 14% plastic waste in daily basis and it is equivalent with 85,000 tons per year. The impact is about 3.2 million tons of plastic are unmanage and dump to the sea. There is still an effort from the government to perform the recycling. According World Economic Forum, about 16% was recycled, but only 2% performed efficiently. The rest of plastic waste was burned (14%), buried in EDS/TDS (4%), and polluted the environment and disturbed the ecosystem (32%).

This reseach finds that the root-cause of this problem is the absence of an effective system in managing plastic waste. In order to overcome these problems, five alternatives were developed, which are reduce, landfill, incineration, recycle, and reuse. The selection of a feasible alternative plastic waste management system to be implemented is carried out using the Analytic Hierarchy Process (AHP) method based on four criteria, which are ease of implementation, effectiveness, operational costs, and the negative impacts that it generates. Based on these factors, recycle is the most feasible system to implement. Industries in Indonesia are expected to work together by creating and implementing a plastic waste management system using a reverse logistics system where the used plastic waste is returned to the industry. Each industry is expected to implement a system that can process types of plastic that differs from each other. Processing results from each industry can be sold or distributed to various industries as raw material for making products according to industrial needs or can be used as raw material for products from the industry itself.

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