Used tires recycle management and processing: a review

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Abstract. The number of used tires in the world is projected to increase in the future due to an incrementing number of cars and motorcycles particularly in developing countries such as Indonesia. This situation can endanger the environment and public health since it poses a high risk for fires. Despite the environmental impacts, used tires present economic values. This can be achieved by processing it into several forms such as tire-derived fuel, asphalt rubber, and rubber-plastic products. Furthermore, to collect used tires from tire users and send it into used tires recycler, management scheme is required. This paper aims to review the development of used tires recycle management and processing. It has been found that several management schemes for recycling used tires have been identified from literature including Extended Producer Responsibility (EPR), Free Market, and Government. Moreover, several processes to recycle used tires were identified, such as: retreading, energy recovery, product recycling, material recycling, and pyrolysis.

1. Introduction
The use of polymeric materials in the world is increasing every year. The tire is one polymeric material which showed a significant increase in the last decade. Reports from several tire and rubber associations, annual tire production is around 1.4 billion units with around 17 million tons of used tires every year [1]. Excessive disposal of used tires can endanger the environment because it poses a high risk of fires. This accumulation of old tires can also lead to the presence of nests of rats, snake, and mosquitoes. The used tire has a complex structure of the materials that consist of natural rubber, synthetic rubber, steel and fiber which cause it as difficult material to recycle [2]. Most of the used tires that are thrown away in disposal presents hazards such as disease and accidental fires [3].

To overcome this, various policies have been made around the world related to the disposal of used tires. For example, the European Union (EU) has established a policy for managing used tires that must be obeyed by every member. This policy requires each country under the European Union to recycle used tires. Used tires cannot be directly reused for other purposes because the tire is configured from several materials such as natural rubber, synthetic rubber, steel, carbon black, and fiber. Then the appropriate process is needed for processing used tires [5]. Furthermore, before these processes are implemented, used tires need to be collected from tire users. This requires a management scheme that organizes the key players who have the responsibility to collect tires from tire users and to recycle it into various products. This paper has the aim to review the management schemes and processing techniques for used tires applied by several countries in literature. To achieve this, the paper is configured into four sections. The second section introduces the research method used in this research. A literature review was used as the research method. The third section presents the result of the review. Finally, in section four, the possibility for future research are discussed.
2. Research methods
The purpose of this research is to review management schemes and processing techniques for recycling used tire and to highlight potential gaps within this field. To achieve these objectives, the review of literature is used as the research method. Papers that focussed on management schemes and technology processing of used tire were reviewed.

2.1. Research process
To achieve the aim of the research, the research process is divided into three steps. The first step focuses on searching and selecting journal papers. The keywords used for searching and selecting the papers were “used tires management” and “recycling tires”. The second process focuses on classifying the papers based on the position of the paper in managing used tire and their technology processing. This is followed by analyzing those papers using thematic analysis. Three themes were applied for used tire management scheme including countries that apply management models, Advantage and Disadvantages and Procedure of management scheme. Whereas, on technology processing of used tires, two themes were applied including economic and environmental aspects. Figure 2 presents the research process.

3. Result and discussion
3.1. Statistic of reviewed papers
In the first step of the research process, 30 papers from various journals have been selected. From these papers, one paper was found that focused to review management scheme of used tires in the European Union [2]. This paper expands the focus of analysis by including other regions such as South Africa, Brazil, Mexico, Japan, and Russia. Table 1 shows the classification of papers based on the management schemes and processing techniques of used tires.

| Classification Themes          | Publications                                      |
|-------------------------------|---------------------------------------------------|
| **Management Scheme of Used Tires** |                                                   |
| Extended Producer Responsibility | [1][5][7][8][9]                                  |
| Free Market System             | [10][11][12][13][14][15][16][17][18][19][20][21] |
| Government System              | [1][2][4][22][15][23][16][17][21][1][4][21][23] |
| Retreading                     | [1][2][12][13][24][25][26][27][28][29][30]      |
| **Processing Techniques of Used Tires** |                                                   |
| Combustion                     | [1][2][4][3][23][31][32]                         |
| Pyrolysis                      | [3][4][22][33][6][18]                            |
| Reuse                          | [2][34][35][36]                                 |
| Shredding                      | [2][4][7][18][12][28][20]                        |
3.2. Used tires recycle management schemes

From recent literature, it was found that three management schemes are used by several countries including extended producer responsibility (EPR), government and free-market. Used tires recycle management scheme displays the procedure and the key players who have responsibilities for collecting, distributing and recycling used tires. Three themes were applied to analyze these schemes including procedure, advantage and disadvantages, and countries applying the management scheme. Figure 3 summarizes the procedure for extended producer responsibility (EPR), government, and free-market schemes.

![Diagram](image-url)
3.2.1. **Extended producer responsibility (EPR) scheme.** In this scheme, responsibility for collecting, distributing and recycling used tires is under tire manufacturers. The responsibility of the tire manufacturer is extended to the post-consumer stage. This means tire manufacturers are required to collect and recycle used tires which are equivalent to the number of tires they sell collectively each year. This collection and recycling activities are financed by applying the environmental contribution to tire users. This cost is passed from producers to tire users [19]. Figure 3 displays the flow of money from tire users to tire producers through tire distributors. Under this scheme, tire producers select the operators who run the collection and recycle process. Tire producers pay those operators for each used tire that have been collected and recycled.

This management scheme is applied by the majority of countries in the European Union. From 28 European Union members, 21 countries have implemented EPR management scheme including Belgium, Bulgaria, Czech Republic, Estonia, Finland, France, Greece, Hungary, Italy, Netherlands, Norway, Poland, Portugal, Romania, Slovenia, Spain, Sweden, and Turkey [12]. From this list, several countries such as Finland, Hungary, and Italy have succeeded to achieve 100 % recycle rate. Furthermore, for Belgium, France, and Portugal, more than 100% recycle rate have been achieved. This is due to the collectors and recyclers have recycled used tires more than their obligation [2].

Ferrao et al. [17] identified several factors affecting the performance of EPR management scheme including the administrative costs, the cost of post-consumer selection, the type of waste flow, the structure of primary and secondary markets, and the availability of the community in the management system. The main advantage of this system is easy to monitor and the high recycle rate. However, this system does not open wide opportunities for more communities to involve in recycling used tires since the operators for collecting and recycling used tires are selected by tire producers. Furthermore, this system must be financed at reasonable costs. If the cost for recycling is too high, it can increase the price of the tire at the consumer level which in turn influencing the sales.

3.2.2. **Free market.** Free Market scheme opens opportunities for any party to involve as operators for recycling used tires (collector, recycler or retreading). In this system, the government sets a law but does not specify the party who has responsibility for recycling used tires. However, all parties involved in the used tire recovery supply chain should act according to the law. United Kingdom, Austria, Croatia, Germany, Ireland, Switzerland are countries that applied free-market scheme. This scheme emerges since used tires have been identified to have big economic values and can be transformed into various products based used tire such as asphalt-based used tire and used tire-derived fuel. Figure 3 displays the flow of money for the free-market scheme are coming from market or industries who buy the products based used tire.

The United Kingdom is one country applied free-market scheme which is driven by government legislation in 1990. Under this legislation, the public needs to ensure that the used tires are not handled illegally, but processing by the authorities who have permission to process the waste [23]. To support this, The British Environmental Agency introduced the National Tire Watch which has the aims to reduce illegal used tires disposal, to support sustainable disposal and recovery, and to reduce the environmental risks from pilling used tires. Furthermore, The British Government implements the Producer Responsibility initiative, which is based on the principle of polluter pays. This means for those who damage the environment, fines will be given. This policy aims to ensure that businesses managed in the free market can be fully responsible for the products produced [38].

The main advantage of this scheme is bigger opportunities for wider communities to involve in the used tire recycling process. Furthermore, the procedure of this scheme is simpler compared with EPR and Government schemes. However, despite the simplicity, this scheme is more difficult to control [2]. For countries where the citizen awareness for the environment is low, there will be limited people who want to involve in used tires recycle process which in turn reducing used tires recycle rate. On the contrary for countries with good citizen awareness for the environment, there will be more people who will actively involve in used tires recycle process particularly if this process presents good economic values.
3.2.3. Government. Under this scheme, the responsibility to recycle used tires belongs to the government. Operators for collecting and recycling used tires are selected by the government. In this scheme, the recycling of used tires is financed by taxes imposed on tire producers. Figure 3 displays the flow of money for the government scheme. Denmark and the Slovak Republic are countries applied government scheme. This scheme is based on a combination of traditional administrative instruments (actions, orders, circulars), and various economic instruments that include taxes, fees, and agreements.

As one country applying government scheme, Denmark applies taxes on various wastes. Regulation related to the management of used tires in Denmark has been announced in 2016 that is called environmental protection law. In this regulation, each city government has a responsibility to recycle used tires. To finance this activity several fees have been applied including tax, the cost for tire collection, administrative provision and the penalty for violation [39].

The main advantage of this scheme is easier to be monitored by the government. To increase the recycling rate, the government can apply tax incentives for tires recycle companies that recycle the used tires more than the target of recycling given by the government. However, the difficulty in this scheme is related to design the appropriate amount of tax for several types of tire which are required different cost to be recycled. On one hand, if the tax is too high, it might reduce the number of tire producers operate and sell their products. On another hand, if the tax too low, it might reduce the number of used tires that will be recycled.

3.3. Used tires recycle process

From the literature, several processes have been implemented to recycle used tires including rethreading, combustion, pyrolysis, and reuse. This section analyses the economic and environmental aspects for used tires recycle processes.

3.3.1. Rethreading. Rethreading is a process to extend the life of the tire by removing the old thread and replacing with the new thread. Only used tires that have passed wear and tear inspection, and have proven to have no damage to the whole body, can be rethreaded. Rethreading can be done using a cold or hot process. The rethreading process presents economic values. According to the Tire Rethread and Repair Information Bureau (TRIB), rethreading can extend 75% until 100% of the age of new tires while the process requires only 30 % of energy and 25% of raw materials for producing new tire [30].

Since rethreading extend the life of tires, a main environmental impact of this process is to reduce material used to produce tires. The rethreading process can save 19-70 % of materials for making tires. Comparing to non-rethreaded tires, rethreaded tires generate 70% material savings due to material recovery and a longer lifespan. Moreover, further savings will be incurred particularly on the consumption of natural resources such as oil and water required for the production of new tires. This also reduces the use of land for natural rubber plantations due to less consumption of natural rubber [41].

3.3.2. Shredding. This process is categorized as mechanical tire milling, which produces rubber materials at various sizes. This process consists of two main steps. The first step focuses to split steel belts and textile layers from the tires. The second step focuses to cut the tires into different sizes. Shredding process produces rubber shredding (crumbs), steel and textile cable. Rubber shredding can be used for certain applications depending on the grain size and level of purity [2]. Used steel is sent for smelting, while textile cables, after cleaning, are burned or used to produce thermal insulation materials for the construction industry.

The disadvantage of the shredding process lies on the wear of the blades for cutting tires. It requires a high cost to renew the blade. Furthermore, during the process, the leaching of ZnO under certain environmental conditions (due to zinc compounds which are part of tire additives) might be occurred [28]. To improve the economic value of the process, liquid nitrogen can be replaced by a compressor system that is capable to chill used tires within 100 °C [2].

One application of rubber shredding is called TDF (tire-derived fuel). Used tires have a heating value of 32 MJ / kg, which makes it competitive compared with other types of fuel such as coal, which has a much lower heating value [32]. For this reason, TDF can be used successfully as a 10-20%
supplementary fuel in properly designed fuel combustors with good combustion control and add-on particulate controls, such as electrostatic precipitators, or fabric filters. Furthermore, a dedicated tire-to-energy facility specifically designed to burn TDF as its only fuel has been demonstrated to achieve emission rates much lower than most solid fuel combustors [16]. The cement industry is one of the biggest consumers for tire-derived fuel. This industry uses tire-derived fuel as an alternative fuel. In addition, used tires are also used as fuel for the production of steam, electricity, paper, lime, and steel. This is because coal combustion with tire-derived fuel increases the thermal efficiency of steam boilers and furnaces, and reduce the amount of emission [2]. Co-combustion in cement kilns is feasible and environmentally safe due to the high temperatures in cement kilns (41200 °C), which ensure the complete combustion of all the tire components. Moreover, the combustion of tires in cement kilns is environmentally safe because of the much lower emission, compared to coal combustion.

3.3.3. Pyrolysis. Pyrolysis is a process to decompose the elastomer contained in the rubber by applying heat to increase the temperature until 400-700 °C. To do this, Tires are hydrolyzed in special pyrolytic furnaces. Tire pyrolysis produces a valuable set of chemical compounds in solid, liquid or gas form, which after appropriate processing can be used in the petrochemical, energy and steel industries. Solid products from pyrolysis are fly ash, soot, residual oxides and sulfides from zinc, silica, and steel. The gas from pyrolysis contains hydrogen, carbon monoxide and dioxide, aliphatic hydrocarbons, and hydrogen sulfide. The liquid from pyrolysis contains aromatic hydrocarbons and oils with high heating value. This liquid, after the removal of contaminated sulfur compounds, is usually mixed with oil and other petrochemical products. Unfortunately, due to the high cost of installation and process improvement, and also because of the uncompetitive product prices, pyrolysis of used tires is rarely used at industrial scale [28]. However, tire Pyrolysis to produce carbon black has been proved as the most eco-friendly and economical technology through a Life cycle analysis. This is achieved through low energy consumption and low emission that is characterized by a low SOx concentration. The gas resulting from pyrolysis can be used as a source of energy for pyrolysis after the start-up period [18].

3.3.4. Reuse. This process focus to apply used tires for other purposes in their original form, without physical or chemical treatment. Because of their shape, size, and good properties such as high elasticity, good vibration, noise and shock, tires are used as inexpensive materials in construction engineering. The used tire can be used to form protective barriers along roads and highways and to protect the seashore edges and curb ramps. Other examples of tire reuse are applying it as fenders for ships, artificial reefs that offer protection for marine organisms, material for road substrates and insulation for building foundations. Furthermore, using used tires as part of products can also improve the properties of those products [16].

For example, the Solerebels company from Ethiopia manufactures footwear with soles made from pieces of tire tread. The Alchemy Goods Company (USA) manufactures handbags, purses, and belts completely from used tires. The positive environmental impact of using this process lies in the reduction of natural resource exploitation since it is replaced by using used tires.

4. Conclusion and possibilities for future research
This paper presents the review of recycling management schemes and processing for used tires. It has been found that three management schemes were implemented to manage the collection and distribution of used tires from tire users to tire recycling companies. From these management schemes, the government scheme and extended producer responsibility (EPR) are identified to be easier to control and to have a high recycling rate. However, the free-market scheme gives opportunities for wider communities to involve in recycling process compared to government and EPR schemes. For the recycling process, four types of processes have been found including rethreading, shredding, pyrolysis and reuse.

There is limited research that focused to investigate management scheme of used tires in developing countries such as Indonesia, India, and Malaysia although the increasing number of cars and motorcycles occur in these countries. Hence, there is an opportunity to investigate the management schemes of used tires in the developing countries. Furthermore, each country might have different
conditions. For example, the number of used tires, the awareness of citizen for the environment, and the infrastructures differ between countries. For this reason, each country might need different management scheme for recycling used tires. Future research is required to evaluate the appropriateness of the management scheme to be applied in a specific country.

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