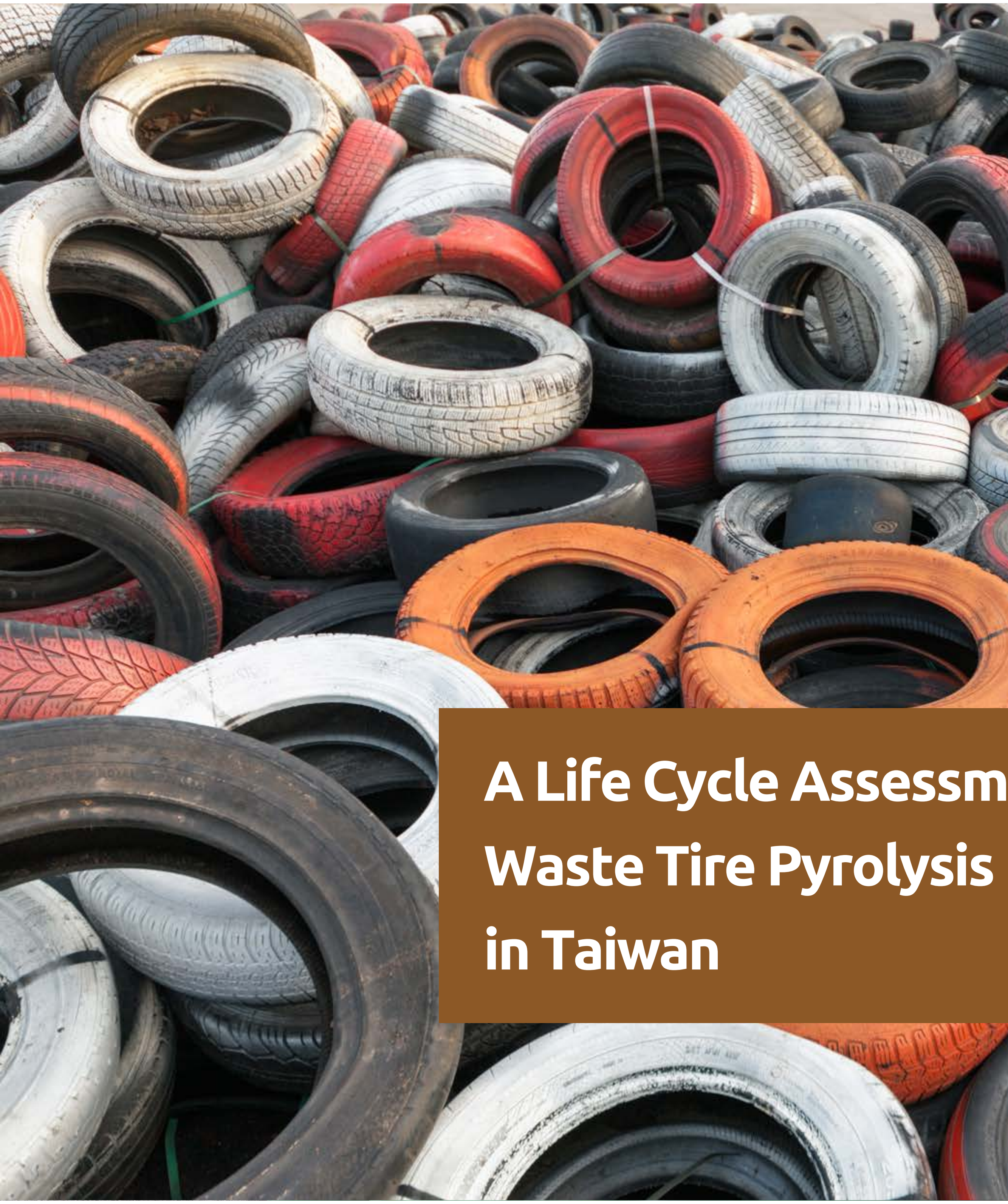
Technical Report



A Life Cycle Assessment of Waste Tire Pyrolysis in Taiwan

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Linking innovations and closing Loops

Table of Contents

Executive Summary

With an ever-rising increase in wheeled travel, from cars and trucks to scooters, tire consumption is also increasing. Currently the world produces 1 billion tons of waste tires each year. Tires are difficult to handle within traditional recycling and create waste management challenges. Pyrolysis is a common method to process waste tires into usable fuel. The process turns waste tires into carbon black and diesel fuel, which solves the problem of waste tires and the need for fuel simultaneously, thereby increasing resource efficiency.

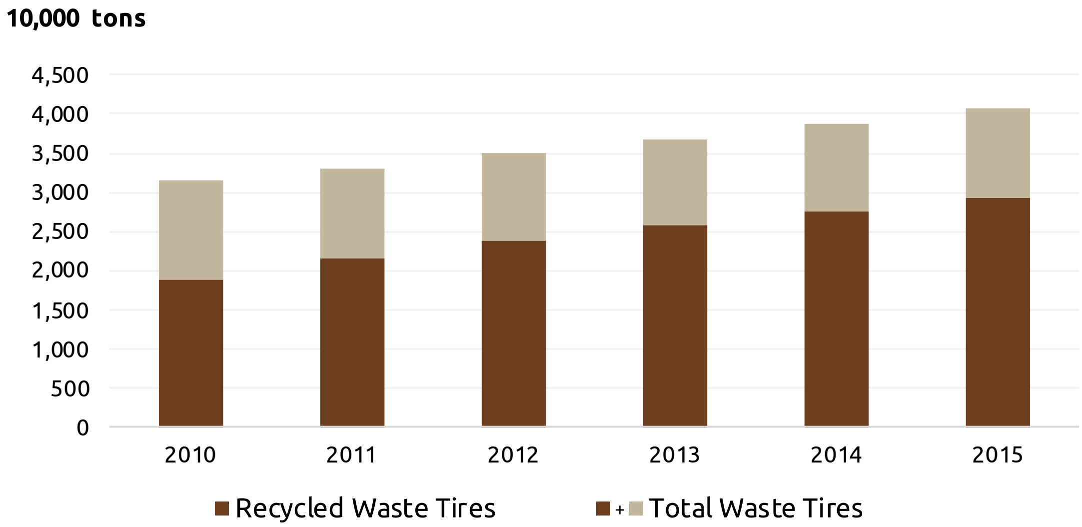
In this report, a life cycle assessment (LCA) approach is used to analyze the impacts of pyrolysis. This impact is compared with other common fuel oil options. The main result shows that environmental impact of pyrolysis oil is 80% of that of heavy oil. Pyrolysis oil is produced through waste tire pyrolysis, not drilling, a method with higher resource impact. However, the preprocess and electricity consumption impact human health due to high percentages of electricity generated through fossil fuels.

Waste Tire Pyrolysis

Mileage traveled by automobiles grows at a rate of 4.1% per year. In 2017, 2.7 billion tires were produced around the world. There are an estimated one billion waste tires waiting to be dealt with. In Taiwan, 12,000 tons of waste tires are produced each year. The unsightly piling of waste tires causes environmental and sanitation problems. 71.5% of waste tires are made into Tire-Derived-Duel (TDF); 14.4% of which are made into recycled materials; 12.5% are turned into fuel oil through the process of pyrolysis; the rest are used as is.

Waste tire pyrolosis produces carbon black with high commercial value and a type of cleaner diesel oil. However, the impact of treating waste tires through pyrolysis needs to be quantified in order to determine the best method for reutilization. Is pyrolosis actually better than TDF?

As the sales of two and four wheeled vehicles continues to soar, waste tires are also accumulating around the globe. In 2015, a total of 40.7 million tons of waste tires were produced globally and 72% of which were recycled. However, the recycle rate differs from region to region. The recycling rate can be up to 80% in Europe and North America, but it is well below average in some regions. Recycling waste tires requires technology and infrastructure, the goal is to not only solve the environmental issue caused by waste tires, but also create reusable energy or resources.



Source: Global Waste Tire Statistics and Forecast

Figure 1 Global waste tire recycling rate

Pyrolysis Oil

Pyrolysis is a thermochemical process in which waste is "combusted" in a zero-oxygen environment breaking it down into other compounds. Within an anoxic environment and temperatures above 450°C (842°F) waste tires are processed into diesel oil and carbon black with syngas as a byproduct. Oil derived from pyrolysis is a substitute for diesel and can be used as fuel oil. Hence, it can be added directly into boilers and incinerators or serve as coagents, boiler fuel or aerospace grade fuels, supplying petroleum refineries and creating a new source of fuel.

The pyrolysis process is shown in **Figure 2**. Waste tires first go through a shredding system separating out rubber, steel wires, and polyester (PET). Then, the rubber enters the pyrolysis system. After condensation and screening, rubber comes out as carbon black and pyrolysis oil. The combustible gases emitted during the process can be captured and reused in the pyrolysis process.

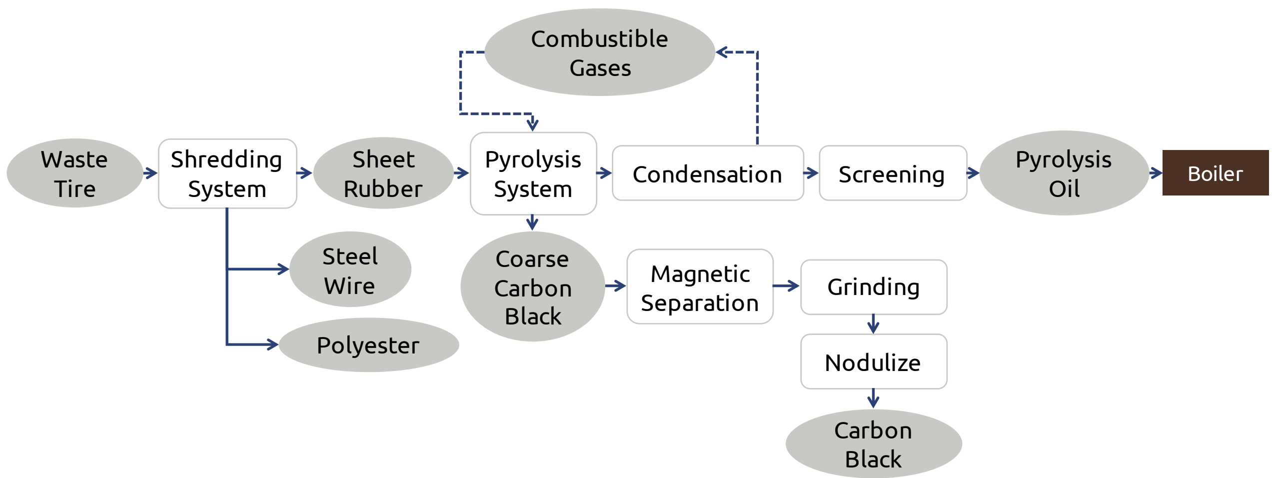


Figure 2 Waste tire pyrolysis and reutilization process

Life Cycle Assessment

According to the definition of ISO 14040, a Life Cycle Assessment (LCA) is the "consolidation and evaluation of inputs and outputs and potential environmental impacts in the life cycle of the production system from the acquisition of raw materials to the final disposal", that is, it serves to assess the impact of the product's overall lifespan on the environment.

The entire life cycle of the product consists of five stages: "raw material", "manufacturing", "transportation", "use" and "end of life". The impact types include human health, ecological impact and resource use. The assessment targets a specific product, process or service, and the evaluation phase can be an overall life cycle or part of the phase, so it can be used as an environmental assessment tool for enterprise product development, or the public sector to develop sustainability policies.

The life cycle assessment of this report is carried out in accordance with the ISO 14040 process. The life cycle impact assessment mode is selected and evaluated by IMPACT 2002+ for environmental impact.

- The IMPACT 2002+ impact assessment method classifies environmental impact into 17 impact categories and summarizes the impact results into the following four main groups: Human health, Ecosystem quality, Climate change, and Resources.

Boundary Settings and Scenarios

The life cycle assessment of this report uses the impact of one ton of pyrolysis oil as its target. The assessment scope includes preprocess, pyrolysis process, heat generating processes, etc. All energy, resources, equipment inputs and emissions in the process must be included in the calculation. According to first-hand data collected for this assessment, 1.3 tons of waste tire can produce one ton of pyrolysis oil. The entire process and the system boundary are shown in **Figure 3**.

In life cycle assessment (LCA), the baseline scenario is replacing a portion of fuel oil (heavy oil) by pyrolysis oil. The recycling scenario settings are as follows:

Scenario 1: Waste tires reutilized as pyrolysis oil, and pyrolysis oil is used as boiler fuel.

Scenario 2: Consider Scenario 1 and the reduction of waste tire piling.

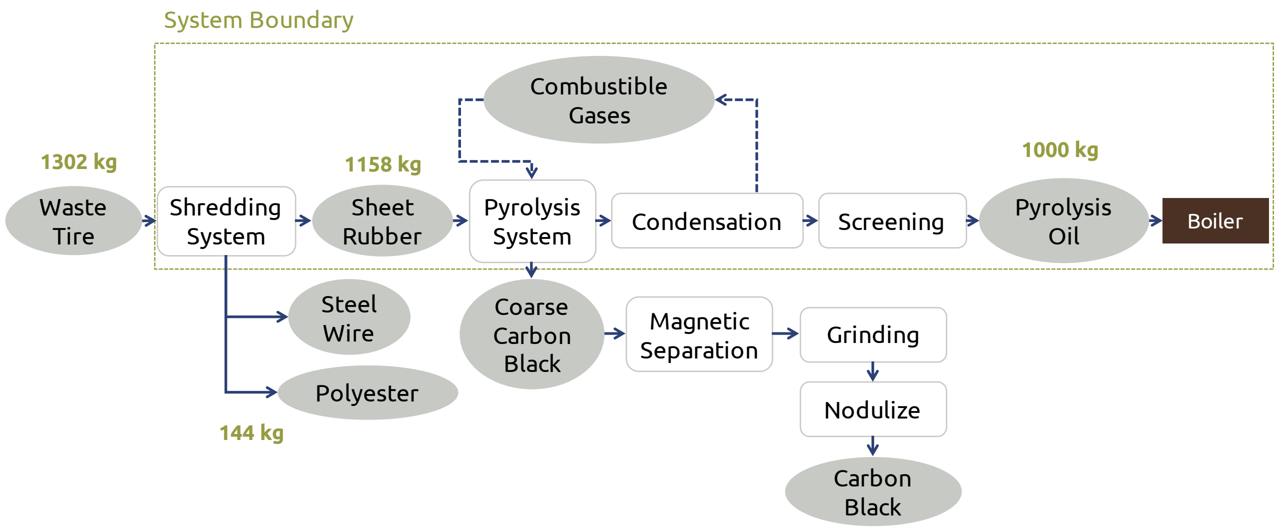


Figure 3 Waste tire reutilization LCA boundary setting

Results and Analysis

Damage to human health is the main impact of pyrolysis oil. The process of pyrolysis impacts human health due to the preprocess and the electricity consumption during the process, which is a consequence of high percentage of electricity generated through fossil fuel. In terms of climate change, there is not difference between the baseline scenario and the pyrolysis oil scenario.

The environmental impact of pyrolysis oil is 20% less than heavy oil. Considering all four groups of impact, the environmental impact of pyrolysis oil is 80% of that of heavy oil. If the decrease of waste tire piling is taken into consideration, pyrolysis oil has 2% of environmental benefit compared to heavy oil.

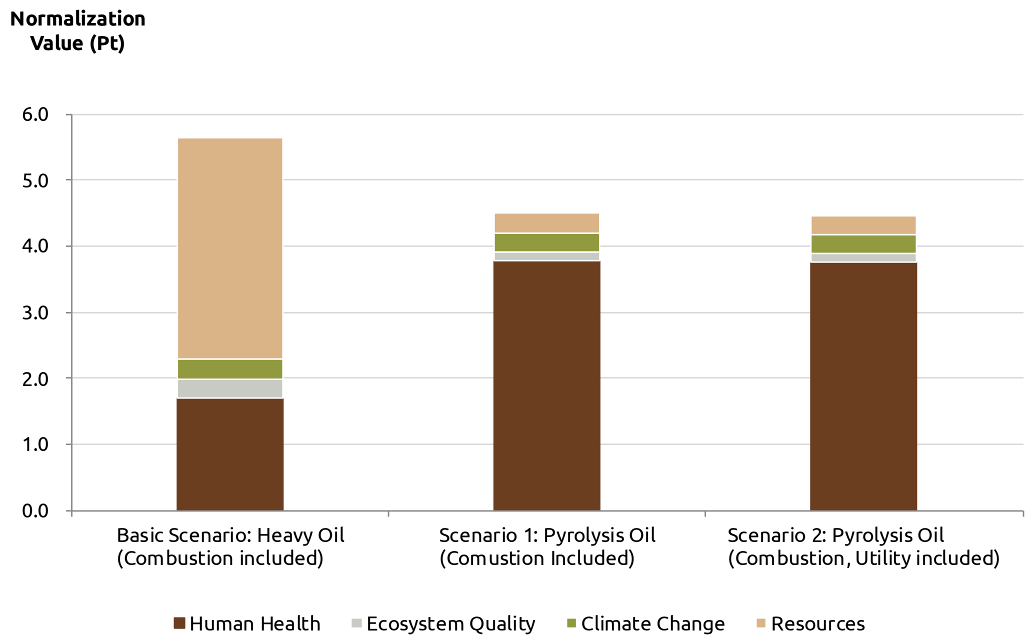


Figure 4 Total impact of LCA result

Results and Analysis

The resource impact of pyrolysis oil is lower than that of heavy oil. Heavy oil and pyrolysis oil impact the environment differently. Heavy oil is obtained through drilling operations. Therefore, the main environmental impact is in diminishing fossil fuel resources. Conversely, pyrolysis oil is produced through the pyrolysis of waste tires, thus the resource impact is minimal.

Environmental impact of desulfurization of pyrolysis oil. The raw material for pyrolysis oil is waste tires, which has high sulfur content. To reduce emission of sulfide into the atmosphere, the manufacturer could include a hydrodesulfurization process to lower sulfur content. However, costs of hydrodesulfurization process are relatively high, which includes a large amount of pyrolysis oil lost during such process. An alternative option is for pyrolysis oil consumers to install pollution control devices. This option decreases the amount of sulfide being released into the atmosphere, conforming to the tighter air quality standard in the future.

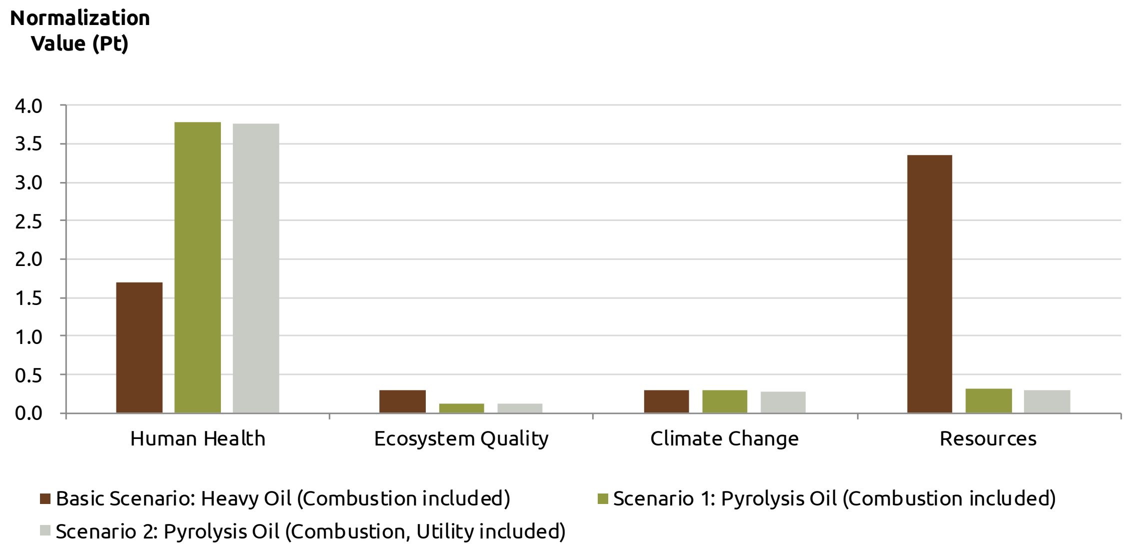


Figure 5 LCA results: comparison by impact type

Conclusions and Suggestions

- Waste tires cause environmental and aesthetic problems. An appropriate method of dealing with the problems is necessary. Through a pyrolysis processes, waste tires can be reutilized and can turned into carbon black and pyrolysis oil with high commercial values.

- This report chooses heavy oil as baseline scenario and analyzes the impact of pyrolysis oil and heavy oil. The life cycle assessment (LCA) model in this report is selected and evaluated by IMPACT 2002+ for environmental impact, including four main categories: human health, ecosystem quality, climate change, and resources.

- Overall studies show that the total impact of pyrolysis oil is only 80% of that heavy oil. Pyrolysis oil is produced with waste tires through the process of pyrolysis, no drilling (with high resource impact) is involved. However, the preprocess of waste tires and electricity consumption impact human health due to a high percentage of electricity currently generated through fossil fuels.

- The pyrolysis process provides a solution to the abundance of waste tires. Such a process serves as a solution to waste tires and produces a substitute for heavy oil, pyrolysis oil, reducing resource and environmental impact.

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