Life Cycle Energy Utilization, Economic Feasibility, and Climate Change Impact Assessment for End-Use Options of Waste Plastic Pyrolysis Oil in Sri Lanka

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Abstract - Plastic pollution is a major environmental issue in developing countries like Sri Lanka due to the increasing plastic use and lack of proper implementation of waste management techniques. Nearly 1.6 million tonnes of non-recyclable plastic waste are generated in Sri Lanka annually, and the majority is disposed in landfill sites. Micro-plastics leaching from these landfills into freshwater could cause ocean deposition and threaten marine life leading to serious environmental impacts. A waste-to-energy technique like pyrolysis can be an attractive solution for non-recyclable plastic waste management in the country. This study analyzes the energy, economic, and environmental feasibility through the aspects of net energy gain, net profit, and climate change impact for five possible end-use scenarios of waste plastic pyrolysis oil. The entire life cycle of the waste plastic pyrolysis process is analyzed that consisting of plastic waste collection and transportation stage, pyrolysis processing stage, and end-use stage of produced pyrolysis oil. Results show that the use of crude pyrolysis oil for electricity generation is not desirable as an end-use option in all aspects. Refining crude pyrolysis oil at a unit basis of 1 m^3 and blending with diesel as commercial fuel reported the highest net energy gain at 24,532 MJ/m^3 with a net profit of Rs. 188,185/m^3 and environmental impact of 6,408 kg CO_2 eq/m^3, implying feasible end-use options of waste plastic pyrolysis oil in practical implementation at commercial scale. Findings in this study could facilitate policy development and decision-making for plastic pollution prevention and management in the country.

Keywords: Life cycle assessment, Waste plastics, Pyrolysis oil, Feasibility assessment

I. INTRODUCTION

Waste plastics have a significant share of Municipal Solid Waste (MSW) in Sri Lanka. The total plastic waste generation is approximately 539,667 tonnes per annum in Sri Lanka where nearly 33% of that plastic waste is collected and largely disposed in landfills [1]. Such landfills can leach micro-plastics into freshwater, causing ocean deposition and threatening the marine life as the ultimate impacts. Currently, the recycling rate is about 3% [1]. Hence, proper management of non-recyclable plastic waste is essential. Pyrolysis technology is an attractive waste to energy technique for non-recyclable plastic waste, which can convert waste plastics into pyrolysis oil, gas, and solid residue.

Thermal degradation of waste plastics in the pyrolysis process can be occurred at 700-900°C temperature. With the involvement of different kind of catalysts, the operating temperature can be reduced to 450-500°C range. Published studies show that catalysts such as zeolite, Y-zeolite, FCC, and MCM-41 can improve the quality of the final product [2]. In addition, parameters like heating rate, retention time, and plastic type also affect the quantity and quality of waste plastic pyrolysis products [2]. Studies report that catalyst involvement at 450°C is optimum for polystyrene (PS), polypropylene (PP) individually and for mixtures with different ratios of PS, PP, PET, and PE where the major product is pyrolysis oil [3]. Under these conditions, the low quantity of generated pyrolysis gas can be used as the heating source for a pyrolysis reactor or for generation of heat and electricity in gas turbine combined system [2]. Produced char content can be sold as an adsorbent for heavy metals from municipal and industrial wastewater and toxic gases [2]. For a country like Sri Lanka, implementation of a commercial scale waste plastic pyrolysis plant would require a proper assessment of energy utilization, economic feasibility, and environmental impacts.

Selection of the most feasible end-use options for the pyrolysis products is also important for successful practical implementation. Studies have reported that pyrolysis can be used for electricity generation by combustion in a diesel engine [4]. Further, pyrolysis oil can be used as an alternative for furnace oil in an industrial boiler or as a fuel for heavy transportation vehicles after blending with conventional diesel at different ratios [5]. Nevertheless, there is no proper comparison among the end-use options reported in the current literature, especially for the context of Sri Lanka. Therefore, this study focuses on an evaluation of energy utilization, economic feasibility, and environmental impacts from possible end use options of waste plastic pyrolysis oil. In this study, establishment of a waste plastic pyrolysis plant in Sri Lanka with five possible end-use options of pyrolysis oil is considered. In terms of environmental impacts, the life cycle greenhouse gas (GHG) emissions are evaluated. Analysis of mass flows and energy flows of various life cycle process stages in this study could support future studies with a dataset for commercial scale implementation of waste plastic pyrolysis plants in the country.

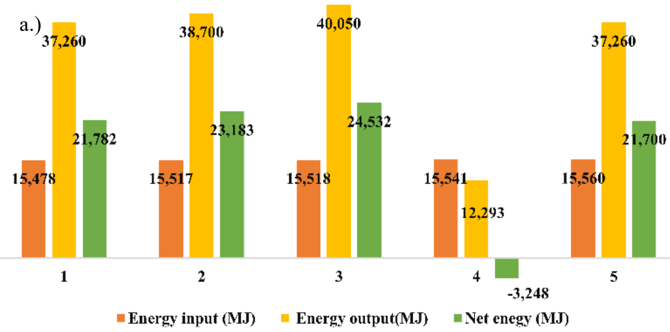
II. MATERIAL AND METHODS

This study adopts ISO 14040-14044:2015 standard Life Cycle Assessment (LCA) methodology to analyze the GHG emissions and global warming impact from each end-use option. The system boundary defined for the study consists with three stages such as plastic waste collection and transportation

stage, pyrolysis processing stage and end-use stage of produced pyrolysis oil stage. The end use stage is further divides into five different scenarios and comparison was done for these five scenarios at the end of the LCA. The five end-use scenarios are,
Scenario 01: Use of crude pyrolysis oil for thermal energy generation
Scenario 02: Refine crude pyrolysis oil at commercial fuel quality
Scenario 03: Refine crude pyrolysis oil at commercial fuel quality and blend with convectional diesel
Scenario 04: Use crude pyrolysis oil for electricity generation
Scenario 05: Use crude pyrolysis oil for refinery mixed with petroleum crude oil.

The functional unit (FU) is taken as 1 m^3 of crude pyrolysis oil production for all inventory calculations. Pyrolysis plant with 10 tonnes per day batch size reactor was considered for the study. The catalytic pyrolysis process is considered that provides an increased quantity of pyrolysis oil at low temperature process condition of 450°C and at a pressure slightly higher than 1 atm. Mixed plastic waste that consists of PS/PP/PE in a ratio 50/25/25% is considered as the feedstock for the plant and the selected catalyst is Natural Zeolite after thermal modification [3]. The pyrolysis product yields were taken as 44% of oil yield, 37% of gas yield, and 19% of ash in weight basis. Batch retention time is considered as 10 hours and heating rate is at 10°C/min for the considered commercial scale plant. For collection and transportation stage, energy requirement was calculated by considering diesel consumption in tractors. For the pyrolysis process stage, calculations were made for pyrolysis plant with and without a refinery stage to purify the crude pyrolysis oil. Through energy input-output analysis and economic calculations, the net energy utilization and net profit were evaluated for the five end-use scenarios and compared.

a.)



b.)

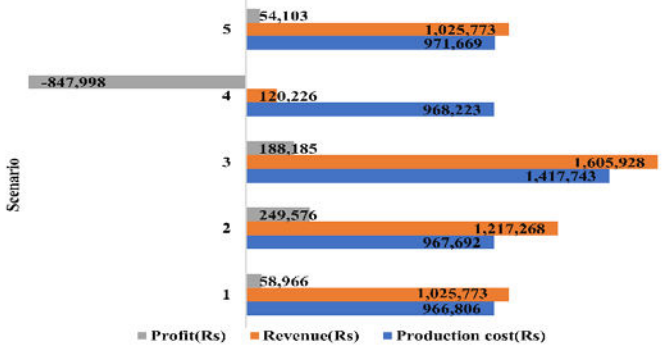


Fig. 1 Energy utilization and Economic analysis for five scenarios (a.) Energy utilization vs scenario (b.) Scenario vs Profit, Production cost, and Revenue (in Rs)

III. RESULTS AND DISCUSSION

Figure 1 shows the scenario comparison of net energy utilization and net profit for the five end-use scenarios. According to the net energy utilization results, scenarios 1, 2, 3, and 5 provide positive net energy gain while only scenario 4 shows a negative net energy gain. It implies that the use of crude pyrolysis oil for electricity generation is energy-wise not desirable as an end-use option. The highest energy gain is showed by the scenario 3, which indicates that the most energy efficient end-use option would be refining crude pyrolysis oil and blending with diesel as commercial fuel. In terms of economic feasibility results, scenario 4 reports an economic loss due to the low selling price of 1 kWh of generated electricity and low efficiency of electricity generating system. The results point out that refining crude pyrolysis oil at commercial fuel quality shows the most economically feasible end-use option for waste plastic pyrolysis oil.

Table 1: GHG emissions in kg CO_2 eq at basis of 1 m^3 of pyrolysis oil

Scenario	1	2	3	4	5
Stage 01	5,108	5,108	5,108	5,108	5,108
Stage 02	1,093	1,298	1,298	1,093	1,093
Stage 03	0	0	2	3,390	11
Total	6,201	6,406	6,408	9,590	6,212

Table 1 lists the stagewise GHG emissions (kg CO_2, eq) in each scenario of waste plastic pyrolysis oil end-use options. The highest total GHG emissions are reported for scenario 04 and 03, respectively. Accordingly, the lowest GHG emission corresponds to the scenario 01, illustrating the most feasible end-use option in terms of environmental emission would be the use of crude pyrolysis oil for thermal energy generation.

IV. CONCLUSION

This study performed a comparative assessment of five end-use scenarios of waste plastic pyrolysis oil in the aspects of net energy gain, net profit, and climate change impact. According to the findings, electricity generation from the produced waste plastic pyrolysis oil is not a desirable end-use option in terms of all aspects. Nevertheless, refining crude pyrolysis oil and blending with diesel as commercial fuel showed more feasibility as an end-use option for waste plastic pyrolysis oil. The Findings can support future implementation of waste plastic pyrolysis at commercial scale in the country.

References

[1] Samarasinghe, S. Pawan Kumar, and C. Visvanathan, “Evaluation of circular economy potential of plastic waste in Sri Lanka,” *Environmental Quality Management*, vol. 31, no. 1, pp. 99–107, Sep. 2021, doi: 10.1002/tqem.21732.

[2] R. Miandad, M. A. Barakat, A. S. Aburiazaiza, M. Rehan, and A. S. Nizami, “Catalytic pyrolysis of plastic waste: A review,” *Process Safety and Environmental Protection*, vol. 102. Institution of Chemical Engineers, pp. 822–838, Jul. 01, 2016. doi: 10.1016/j.psep.2016.06.022.

[3] R. Miandad, M. A. Barakat, A. S. Aburiazaiza, M. Rehan, I. M. I. Ismail, and A. S. Nizami, “Effect of plastic waste types on pyrolysis liquid oil,” *International Biodeterioration and Biodegradation*, vol. 119, pp. 239–252, Apr. 2017, doi: 10.1016/j.ibiod.2016.09.017.

[4] S. Lee, K. Yoshida, and K. Yoshikawa, “Application of Waste Plastic Pyrolysis Oil in a Direct Injection Diesel Engine: For a Small Scale Non-Grid Electrification,” *Energy and Environment Research*, vol. 5, no. 1, Mar. 2015, doi: 10.5539/eer.v5n1p18.

[5] I. Kalargaris, G. Tian, and S. Gu, “Combustion, performance and emission analysis of a DI diesel engine using plastic pyrolysis oil,” *Fuel Processing Technology*, vol. 157, pp. 108–115, Mar. 2017, doi: 10.1016/j.fuproc.2016.11.016.