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(RESEARCH ARTICLE)

A Comparative study of carbon footprints of LDPE plastic waste landfilling and valorization to gasoline for generator usage

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Abstract

The impact of greenhouse gas emissions from improper waste disposal is widespread and profound; affecting environment, economies, public health, and the global climate system. This study compared the carbon footprint associated with the conversion of plastic wastes into gasoline for fueling generator, and the carbon footprint for using unsanitary landfill to dispose of the plastic wastes. Pyrolysis fixed bed reactor was fabricated for the conversion of 10 kg of ground LDPE to 400 ml of liquid oil from which 213.33 ml of gasoline was obtained. The findings indicated that that usage of unsanitary landfill for the disposal of 1000 kg of LDPE plastic wastes led to the emission of 1,188 kg GHG per megajoule (MJ) while usage of pyrolysis process for the conversion of 1000 kg of plastic wastes to gasoline for generator usage resulted in the emission of 1,203.113 kg GHG/MJ. Both waste management techniques emitted a significant amount of greenhouse gases, with pyrolysis emitting a marginally higher amount. The higher emission from the pyrolysis process might be due to the ineffective design of air-fuel mixing port of the pyrolysis furnace, as well as, the usage of liquefied petroleum gas as fuel for the pyrolysis process. Further improvement on the design and process parameters could make the carbon footprint of using pyrolysis technique for plastic waste management to be drastically reduced, thereby, making the technique to be environmentally friendly and sustainable.

Keywords: Carbon footprint; Greenhouse gases; Plastic wastes; Valorization; Sustainable environment

1. Introduction

The increasing rate of plastic usage due to various factors, including population growth, urbanization, lifestyle changes, and evolving socio-economic conditions has led to a corresponding rise in plastic waste generation. This poses significant challenges for disposal, especially considering that plastics, including low-density polyethylene (LDPE), take hundreds of years to degrade, which exacerbates the environmental burden [1, 2]. Large quantity of plastic waste produced across the world is composed of plastics, including high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP), polyethylene terephthalate (PET), polystyrene, and polyvinyl chloride (PVC), with global production about 15, 18, 21, 7, 8 and 17 %, respectively [3]. These percentages reflect the varied applications of plastics across industries, such as packaging, construction, textiles, and consumer goods. LDPE, for instance, is commonly used in packaging, especially for products like water sachets, while PET is widely used in beverage bottles. Polystyrene and PVC have applications in various sectors like food containers and construction materials. The high proportion of plastic waste made up of these materials underscores the challenges of plastic waste management, as each type of plastic requires specific methods for recycling or disposal. About 400 million tonnes of plastics including single-

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use plastics (drink bottles, wet wipes, cotton bud sticks, sanitary items) are produced globally every year [4, 5] with about 40 % of it landfilled [5, 6]. LDPE is mostly used in packaging many goods, including packaging of potable water locally known as *pure water* in Nigeria. The use of LDPE as water sachet in Nigeria is popular in Nigerian communities, as it is viewed as a practical solution to economic challenges faced by the country. However, the LDPE sachets are often found littering and defacing the environment since LDPE plastics have extremely low degradation rate [7, 8, 9].

Plastic waste disposal is a major waste management challenge worldwide because of its abundance, widespread presence, and versatility. Furthermore, plastics contain chemicals that can have harmful effects on both animal and human health when consumed [10]. In developing countries, including Nigeria, the absence of effective waste management systems leads to the use of harmful disposal methods such as burning, ocean dumping, and unsanitary landfilling. A significant amount of plastic waste is either dumped in landfills, incinerated, or ends up contaminating the environment, including land and water bodies [11, 12]. As plastics eventually degrade, they fragment into smaller particles known as microplastics, which can be consumed by wildlife and enter the food chain, resulting in indirect environmental and health consequences [13 - 18). Improper plastic waste disposal has led to a range of environmental issues, including flooding, clogged drainage systems, global warming, and threats to biodiversity. The carbon footprint of landfilling plastic waste from human consumption of food and products plays a major role in climate change, environmental degradation, and resource depletion. To minimize the harmful environmental effects of plastic waste landfilling, an efficient waste management system is necessary. The disposal of plastic waste, typically through incineration or landfilling, releases more greenhouse gases into the atmosphere. Waste combustion produces thousands of harmful pollutants, particularly affecting people living near incineration facilities [5]. Therefore, alternative methods for effective plastic waste disposal are essential.

Effective plastic waste management, using techniques such as pyrolysis, can help reduce the carbon footprint of plastics and lessen their environmental impact. Many researchers have selected pyrolysis as an effective method for plastic waste disposal, as it promotes a circular economy approach. Pyrolysis is the process of breaking down long-chain polymer molecules into smaller, simpler molecules through the application of heat and pressure. The process requires high heat for a short duration and occurs in the absence of oxygen. The three main products produced during pyrolysis are oil, gas, and char, which are valuable to industries, particularly in production and refining processes [19, 20, 12, 21]. Pyrolysis gas can be further processed into fuels and chemicals or used as an energy source within the process itself. Meanwhile, pyrolysis oil can be applied in various settings, such as furnaces, boilers, turbines, and diesel engines, without the need for upgrading or treatment. Although he oil produced from plastic waste typically contains higher sulfur levels compared to conventional fuel oil [22], The loil has combustible properties similar to conventional diesel, making it a viable alternative to fossil fuels for power generation [23, 5, 11]. The char produced from the pyrolysis process can be utilized for heating, soil and water remediation, carbon sequestration, and as printer black ink. Plastic pyrolysis is an effective method for managing plastic waste and helping prevent the depletion of fossil fuels.

The emission-reducing potential of the pyrolysis technique for plastic waste management can be assessed by calculating its carbon footprint. This refers to the total amount of greenhouse gases produced directly and indirectly to support human activities, typically expressed in equivalent tons of carbon dioxide (CO2). It represents the sum of all CO_2 emissions induced by human activities over a specific period, usually one year. For example, the calculation of greenhouse gas emissions (GHG_{em}) contributed by an individual household from the disposal of 1000 kg of plastic waste in a developing country can be represented by Equation 1, where the emission factor for plastic is 3.3. The GHG_{em} from the use of a household generator is provided by Equation 2, while the GHG_{em} from burning liquefied petroleum gas (LPG) required for heating the feedstock is given by Equation 3. In these expressions for determining carbon footprint, carbon dioxide equivalents ($CO_{2\ eq}$), which account for all greenhouse gases, are used.

$$GHG_{em} = \frac{Number\ of\ bins / week * Average\ mass\ of\ waste / year * Emission\ factor}{\text{Number of Household Occupants}} \quad \text{.....................(1)}$$

$$GHG_{em} = \frac{12\, months * Volume\ of\ fuel(Litres)/month * Energy\ density\ of\ fuel * Emission\ factor\ of\ fuel}{\text{Number of Household Occupants}} \quad \text{................ (2)}$$

$$GHG_{em} = \frac{12\, months * Volume\ of\ fuel(Litres)/month * Energy\ density\ of\ fuel * Emission\ factor\ of\ fuel}{\text{Number of Household Occupants}} \quad \text{................ (3)}$$

Different researchers have worked on using pyrolysis technique for plastic waste management. For example, Kabeyi & Olanrewaju [22] established the feasibility of waste plastic pyrolysis to produce fuel from a wide range of plastic materials, such as, high-density polyethylene (HDPE), polyethylene terephthalate (PET), polystyrene (PS), and polypropylene (PP). In addition, the various studies conducted by Patni et al. [24], Verma et al. [25], Kabeyi & Olanrewaju [26], Güngör et al. [27] and Kaimal & Vijayabalan [28] indicated that the brake thermal efficiency of pyrolysis oil, when used as an engine fuel, was comparable to that of conventional diesel though the engine emissions were notably higher with pyrolysis oil. Also, Sharuddin et al. [29] observed that the physical properties including calorific value, density, viscosity, and flash point of pyrolysis oil produced from different plastic wastes (PET, HDPE, PVC, LDPE, PP, PS) were found comparable with commercial gasoline and diesel [29]. Although several studies have been conducted on the production of diesel oil and gasoline from plastic wastes, there is dearth of studies on the comparative study of emissions when unsanitary landfill and pyrolysis are used for plastic waste management. Therefore, this study examined the difference in carbon footprints for conversion of LDPE plastic wastes into gasoline for generator usage, and when landfilling is used for plastic waste disposal.

2. Material and methods

2.1. Experimental material

The ground LDPE plastic waste, sourced from a local recycler in the Idimu area of Lagos State, Nigeria, served as the primary feedstock for the research study. Approximately 10 kg of the feedstock was measured and placed into a fabricated pyrolysis reactor made of 12 mm thick mild steel, with a height of 1000 mm and a diameter of 300 mm. A 20 mm thick perforated steel rod was integrated into the reactor to ensure uniform heat transfer from the gas source into the reactor. The joints and fittings of the pipelines and flange plates were sealed using a high-temperature adjustable gasket. The pyrolysis reactor, insulated with firebricks to minimize heat loss, featured a feeder with a 300 mm diameter, which was covered by a flat plate secured with nuts and bolts. The pyrolysis system included a gas-fired furnace, a pyrolysis reactor, a heavy oil condenser, a light oil condenser, and two scrubbers designed to eliminate impurities from the pyrolytic gas (Figure 1). There were pipes of 5 mm thickness that connected the reactor, heavy and light oil condensers, as well as, scrubbers together. A solar-powered temperature sensor was attached to the pyrolysis reactor to monitor. Pipes with a thickness of 5 mm connected the reactor, heavy and light oil condensers, and scrubbers. A solar-powered temperature sensor was installed on the pyrolysis reactor to monitor the temperature the pyrolysis process. The LPG cylinder provided the gas used to heat the feedstock in the reactor. The gaseous products from the scrubbers were collected in a gas bag via a rubber tube.

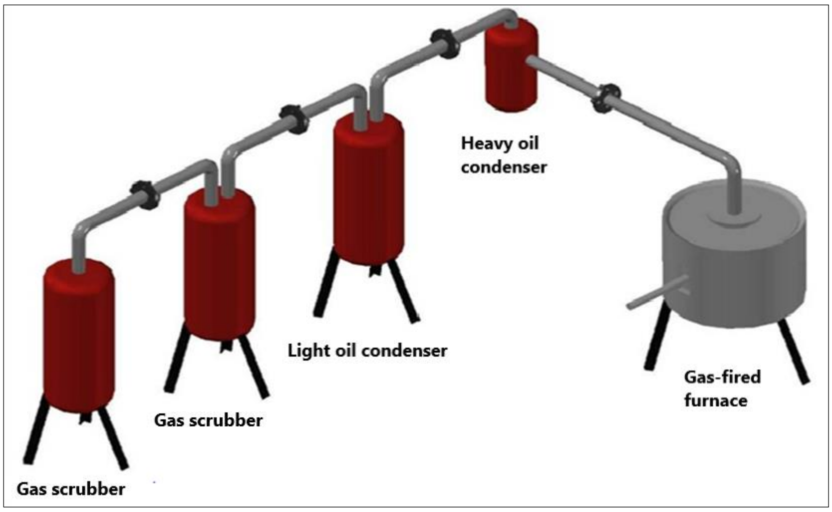

Figure 1 AutoCAD drawing of pyrolysis system Setup

2.2. Experimental procedure

The reactor, containing 10 kg of LDPE plastic, was heated with LPG gas, causing the temperature of the LDPE to increase from its initial temperature of 35.5°C. Gas production was observed when the LDPE reached a temperature of 345°C, approximately 3 hours into the experiment. Liquid production was noticed at 353°C, 45 minutes after the gas production had begun. The total volume of liquid oil produced was approximately 400 ml, of which 75 ml was extracted for further separation via fractional distillation. The liquid product, believed to be diesel from the pyrolysis of LDPE, was placed in a round-bottom flask, clamped to a retort stand, and gradually heated until it began to boil. The boiling point at this stage was observed to be 27°C. The vapor emerging from the flask traveled through the delivery tube and condensed in a test tube, which was placed inside a cold-water bath within a beaker. After about 7 minutes, when the liquid stopped boiling, the Bunsen burner flame was increased, causing the liquid to resume boiling at a temperature of 42°C. The vaporized liquid condensed in another test tube placed in a cold-water bath inside a beaker. This process continued for about five minutes before the boiling ceased. The Bunsen burner flame was maintained at this level, and the thermometer reading remained steady at 42°C for 10 minutes. Afterward, the Bunsen burner flame was increased again, causing the remaining liquid in the flask to begin boiling. At this point, the thermometer reading reached 75°C. The vapor emerging from the flask passed through the delivery tube and condensed in another test tube, which was placed in a beaker filled with cold water. At this point, the thermometer reading reached 75°C. The vapor emerging from the flask passed through the delivery tube and condensed in another test tube, which was placed in a beaker filled with cold water.

2.3. Greenhouse gas emission (GHG_{em}) from landfilling of 1000 kg of plastic waste

According to Energy Research Centre, 2012 [30 - 33], emission factor for every 1000 kg of plastic waste disposed of is 3.3. therefore, the greenhouse gas emission can be calculated using Equation 1:

$$GHG_{em} = \frac{Number\ of\ bins / week * Average\ mass\ of\ waste / year * Emission\ factor}{\text{Number of Household Occupants}}$$

$$= \frac{30 * 12 * tons\ of\ CO2_e}{\text{Person x day}}$$

This implies that every household or individual disposing of 1000 kg of plastic waste is emitting a greenhouse gas emission (GHGem), which can be calculated by multiplying the amount of plastic waste by the emission factor of 3.3:

GHG_{em}, = 30 x 12 x 3.3 kg GHG /MJ = 1188 kg GHG/ MJ

2.4. Greenhouse gas emission (GHG_{em}) from the use of household generator

The Greenhouse gas emission (GHG_{em}) from the use of household generator is given in Equation 2:

$$GHG_{em} = \frac{12\, months * Volume\ of\ fuel(Litres) / month * Energy\ density\ of\ fuel * Emission\ factor\ of\ fuel}{\text{Number of Household Occupants}}$$

From the 10 kg of LDPE plastic wastes used as feedstock in this research study, 400 ml of liquid oil was obtained. About 75 ml of the liquid oil obtained from the pyrolysis process yielded 40 ml of gasoline. This indicates that 400 ml of liquid oil will produce 213.33 ml of gasoline. Therefore, 10 kg of plastic waste will yield 213.33 ml of gasoline, and 1000 kg of plastic waste will yield 21, 333 ml of gasoline, which is equivalent to 21.33 liters.

If 21.33 liters of gasoline is used to power a generator, and given the emission factor (0.069549 kg/MJ) and energy density (34.2 MJ/L) of the gasoline[[30 - 33], we can calculate the greenhouse gas emissions and the total energy produced. Equation 2 gives the greenhouse gases emission from the use of household generator:

$$GHG_{em} = \frac{12\, months * Volume\ of\ fuel(Litres) / month * Energy\ density\ of\ fuel * Emission\ factor\ of\ fuel}{\text{Number of Household Occupants}}$$

= (12 x 21.33 x 34.2 x 0.069549) GHG kg/L = 608.82 GHG kg/L

= 24.353 GHG kg/MJ (since 1 litre ≈ 25 MJ of energy from LPG)

This implies that the greenhouse gas emission from using 1000 kg of plastic waste to obtain 21.33 L of gasoline for fueling generator is 24.353 GHG kg/MJ

2.5. Greenhouse gas emission (GHGem) from using liquefied petroleum gas (LPG) as fuel for the pyrolysis process

The greenhouse gas emission from burning liquefied petroleum gas as fuel for heating is given in Equation 3:

$$GHG_{em} = \frac{12\, months * Volume\, of\ \ fuel(Litres)/month * Energy\, density\, of\ \ fuel * Emission\ \ factor\, of\ \ fuel}{\text{Number of Household Occupants}}$$

The amount of LPG used to produce the liquid oil from the pyrolysis reaction and distillation process is estimated as 4 kg which is equivalent to 7.84 L (Since 1 kg LPG gas is 1.96 litres of LPG). This indicated that 7.84 L of LPG was required for the pyrolysis of 10 kg of LDPE plastic wastes. Therefore, for 1000 kg of LDPE plastic wastes, 784 L of LPG would be required. The energy density and emission factor of LPG are given as 49.6 MJ/kg and 0.063152 kg GHG/ MJ, respectively. This implies that the greenhouse gas emission (GHG_{em}) from using liquefied petroleum gas (LPG) as fuel for the pyrolysis of 1000 kg of LDPE plastic wastes is:

$$GHG_{em} = \frac{12\, months * Volume\, of\ \ fuel(Litres)/month * Energy\, density\, of\ \ fuel * Emission\ \ factor\, of\ \ fuel}{\text{Number of Household Occupants}}$$

= (12 x 784 x 49.6 x 0.063152) = 29,469 GHG kg/L = 1,178.76 GHG kg/MJ (since 1 litre ≈ 25 MJ of energy from LPG)

3. Results and discussion

Table 1 shows the summary of results obtained from the comparison between the carbon footprint of two waste management techniques, including usage of unsanitary landfill for LGPE plastic waste disposal, and pyrolysis process for conversion of LDPE plastic waste to gasoline for generator usage. Their corresponding greenhouse gas (GHG) emissions were measured in kg GHG per megajoule (MJ). A comparison analysis of the two waste management techniques based on their greenhouse gas (GHG) emissions indicates that usage of Unsanitary Landfill for the disposal of 1000 kg of LDPE plastic wastes led to the emission of 1,188 kg GHG per megajoule (MJ) indicates that this method is quite harmful to the environment while usage of pyrolysis process for the conversion of 1000 kg of plastic waste to gasoline for generator usage caused the emission of 1,203.113 kg GHG/MJ. Regarding impact on the environment; both waste management techniques emit a significant amount of greenhouse gases, with pyrolysis emitting a marginally higher amount (1,203.113 kg GHG/MJ) compared to unsanitary landfills (1,188 kg GHG/MJ). Although pyrolysis might be considered more environmentally friendly compared to landfills since it can convert waste into useful products like fuels or chemicals; the emissions are still significant. The emission of 1,203.113 kg GHG per MJ is slightly higher than that of landfills, which suggests that the pyrolysis process might still involve considerable GHG release, especially if the energy required for the process is not derived from clean sources, as in the case of this study where LPG was used as the energy source for the pyrolysis process. Given that pyrolysis involves energy-intensive processes, it is possible that its higher emissions come from the fossil fuel (LPG) energy source used. Additionally, the design of the air to fuel mixture port was not efficient leading to incomplete combustion, and consequent energy waste during the pyrolysis process. The emissions from pyrolysis might be reduced by using renewable energy sources for the process. Also, optimizing the process to increase efficiency and reduce waste during the transformation of materials could help mitigate GHG emissions. Regarding the usage of landfill waste management technique, controlled landfills with proper waste management techniques such as using liners, leachate collection and gas collection; can also lower the environmental impact

Table 1 Comparison of carbon footprint of LDPE plastic waste landfilling and valorization to gasoline for generator usage

S/No	**Waste Management Techniques**	**Waste Management Techniques for 1000 kg of LDPE plastic wastes**	**Greenhouse gas emission (GHG_{em}) equivalent**	**Total greenhouse gas emission (GHG_{em}) equivalent**
1	Usage of unsanitary landfill	Landfilling of 1000 kg of LDPE plastic wastes	1,188 kg GHG/ MJ	1,188 kg GHG/ MJ
2	Usage of pyrolysis process	Greenhouse gas emission (GHG_{em}) from using 21.33 L gasoline obtained from 1000 kg of LDPE plastic wastes to fuel generator	24. 353 kg GHG / MJ	1, 203. 113 kg GHG / MJ
		Greenhouse gas emission (GHG_{em}) from using liquefied petroleum gas (LPG) as fuel for the pyrolysis process	1, 178.76 GHG kg/ MJ	

4. Conclusion

This study, which focused on the comparison between two waste management techniques, unsanitary landfilling and pyrolysis of LDPE plastic waste to produce gasoline for generator usage; reveals that both methods emit significant greenhouse gases. Pyrolysis results in a slightly higher emission (1,203.113 kg GHG/MJ) compared to unsanitary landfilling (1,188 kg GHG/MJ). Despite pyrolysis being potentially more environmentally friendly by converting waste into useful products like fuels, the process still releases considerable GHG emissions, primarily due to the use of liquefied petroleum gas (LPG) as an energy source and inefficiencies in the air-fuel mixture design during pyrolysis. A comparison of these techniques or how they might impact overall sustainability indicates that neither technique is particularly ideal from the sustainable perspective, as both produce high GHG emissions. However, between the two, pyrolysis, though having marginally higher GHG emissions than unsanitary landfill, could be more favourable if non-fossil fuel is used for the pyrolysis process in addition to improving the design for the air to fuel ratio. With improved design and process parameters, the carbon footprint of the pyrolysis technique could be significantly reduced, making it a more environmentally friendly and sustainable method for plastic waste management. Similarly, controlled landfills with proper management techniques could minimize the environmental impact of the plastic waste disposal.

Compliance with ethical standards

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Disclosure of conflict of interest

Authors declare that there are no conflict of interest.

References

[1] Kabeyi MJB. & Oludolapo AO. Viability of wellhead power plants as substitutes of permanent power plants in grid electricity generation, in Proceedings of the 2nd African International Conference on Industrial Engineering and Operations Management, Harare, Zimbabwe, 2020.

[2] Labaki M, Jeguirim, M. Thermochemical conversion of waste tyres—a review. Environmental Science and Pollution Research 2017; 24 (11): 9962–9992.

[3] Hahladakis, JN, Velis CA, Weber R, Iacovidou E, Purnell P. An overview of chemical additives present in plastics: migration, release, fate and environmental impact during their use, disposal and recycling. Journal of Hazardous Materials 2018; 344, 179–199.

[4] Devasahayam S, Bhaskar-Raju G, Hussain CM. Utilization and recycling of end-of-life plastics for sustainable and clean industrial processes including the iron and steel industry. Materials Science for Energy Technologies 2019; 2 (3): 634–646.

[5] Fahim I, Mohsen O, ElKayaly D. Production of fuel from plastic waste: a feasible business. Polymers 2021; 13(6): p. 915.

[6] Raja A, Murali A. Conversion of plastic wastes into fuels. Journal of Materials Science and Engineering B, 2011;1, 86–89.

[7] Kabeyi, MJB, Olarenwaju, OA. Performance analysis of an open cycle gas turbine power plant in grid electricity generation. IEE International Conference or Industrial Engineering and Engineering Management (IEM) 2020; Singapore, 524 -529.

[8] University of Oxford. Turning plastic waste into hydrogen and high-value carbons. University of Oxford 2021. Available from https:// www.ox.ac.uk/news/2020-10-13-turning -plastic-waste-hydrogen-and-high-value-carbons.

[9] Ambuchi DO. Plastic waste management in Kenya an evaluation of policies and regulations on plastic bags and plastic bottles waste in Nairobi, [Ph. D. thesis], Master of Arts in Environmental Planning and Management, University of Nairobi, Nairobi, Kenya, 2006.

[10] Kunwa B, Cheng, HN, Chandrashekaran, SR, Sharma, BK. Plastics to fuel: a review," Renewable and Sustainable Energy Reviews 2016; 54, 421–428.

[11] Kabeyi, MJK. & Olanrewaju, OA. Hydrogen and carbon nanotubes from pyrolysis-catalysis of waste plastics: A Review. Waste and Biomass Valorisation 2021; 12, (1), 1–28,

[12] Bernardo CA, Simões, CL, & Costa LMP. Environmental and economic life cycle analysis of plastic waste management options, in AIP Conference Proceedings 2016; 1779 (1):140001, Dhaka, Bangladesh.

[13] Campanale C, Massarelli C, Savino I, Locaputo V, Uricchio VF. A detailed review study on potential effects of microplastics and additives of concern on human health. Int. J. Environ. Res. Public Health 2020; (17): 1212.

[14] http://dx.doi.org/10.3390/ijerph17041212.

[15] Hassan F, Prasetya KD., Hanun JN, Bui HM, Rajendran S, Kataria N, Khoo KS, Wang YF, You, SJ, & Jiang, JJ. Microplastic contamination in sewage sludge: Abundance, characeristics, and impacts on the environment and human health. Environ. Technol. Innov. 2023; 31, 103176.

[16] http://dx.doi.org/10.1016/j.eti.2023.103176

[17] Chen YN, Rani A, Chiang, CY, Kim H, Pan SY. Monitoring, control and assessment of microplastics in bioenvironmental systems. Environ. Technol. Innov. 2023; 32: 103250. http://dx.doi.org/10.1016/j.eti.2023.103250.

[18] Osman AI, Hosny M, Eltaweil AS, Omar S, Elgarahy AM, Farghali M, Yap PS, Wu YS, Nagandran S, Batumalaie K, Gopinath SCB, John OD, Sekar M, Saikia T, Karunanithi P, Hatta MHM, Akinyede KA. Microplastic sources, formation, toxicity and remediation: a review. Environ. Chem. Lett. 2023; 21, 2129–2169. http://dx.doi.org/10.1007/s10311-023-01593-3.

[19] Alsabri A, Tahir F, Al-Ghamdi SG. Environmental impacts of polypropylene (PP) production and prospects of its recycling in the GCC region. Mater. Today Proc. 2022; 56, 2245–2251. http://dx.doi.org/10.1016/j.matpr.2021.11.574.

[20] Zhou Z, Tang Y, Dong J, Chi Y, Ni M, Li N, Zhang Y. Environmental performance evolution of municipal solid waste management by life cycle assessment in Hangzhou, China. J. Environ. Manage. 2018; 227, 23–33.

[21] http://dx.doi.org/10.1016/j.jenvman.2018.08.083

[22] Kabeyi MJB, Olanrewaju OA. Diesel to gas engine powerplant conversion: a review and preliminary design for an operating power plant," Journal of Energy Management and Technology 2013; 7 (2): 103–115.

[23] Bekele W, Amedie W, Salehudres Z. Design of pyrolysis reactor for waste plastic recycling. Engineering and Applied Sciences 2020; 5 (5): 92–97.

[24] Kabeyi MJB. & Olanrewaju OA. Dual cycle cogeneration plant for an operating diesel powerplant," in Proceedings of the 11th Annual International Conference on Industrial Engineering and Operations Management, 2021, Singapore.

[25] Kabeyi, MJB, & Olanrewaju OA. Review and Design Overview of Plastic Waste-to-Pyrolysis Oil Conversion with Implications on the Energy. Journal of Energy 2023; 1, 1-23: 1821129. https://doi.org/10.1155/2023/1821129.

[26] Eze WU, Umunakwe R. Obasi HC, Ugbaja MI, Uche CC, Madufor IC. Plastics waste management: a review of pyrolysis technology. Clean Technologies and Recycling 2021; 1(1): 50–69.

[27] Patni N, Shah P, Agarwal S, Singhal P. Alternate strategies for conversion of waste plastic to fuels. ISRN Renewable Energy 2013; Article ID 902053, 7 pages.

[28] Verma A, Raghuvansi A, Quraishi MA, Tirkey JV, Verma C. Engine fuel production from waste plastic pyrolysis (WPO) and performance evaluation in a CI engine with diesel blend. Journal of Materials and Environmental Sciences 2018; 9 (6): 1712–1721,

[29] Kabeyi MJB. & Olanrewaju OA. Diesel to gas engine power plant conversion: a review and preliminary design for an operating power plant. Journal of Energy Management and Technology 2013; 7 (2): 103–115.

[30] Güngör C, Serin H, Özcanlı M, Serin S, Aydın K. Engine performance and emission characteristics of plastic oil produced from waste polyethylene and its blends with diesel fuel. International Journal of Green Energy 2015; 12 (1): 98–105.

[31] Kaimal VK, Vijayabalan P. An investigation on the effects of using DEE additive in a DI diesel engine fueled with waste plastic oil. Fuel 2016; 180, 90–96.

[32] Sharuddin SDA, Abnisa F, Wan-Daud WMA, Aroua, MK. A review on pyrolysis of plastic wastes. Energy Conversion and Management 2016; 115, 308–326.

[33] 2012 Guidelines to Defra / DECC‟s GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors Department for Environment, Food and Rural Affairs Nobel House 17 Smith Square London SW1P 3JR

[34] Solomon S, Qin D, Manning M, Chen Z, Marquis M, Avery KB, Tignor M, Miller HL. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Cambridge University Press, Cambridge, United Kingdom Table 2.14. Lifetimes, radiative efficiencies and direct (except for CH4) global warming potentials (GWP) relative to CO2, 2007. Available from

[35] http://www.ipcc.ch/ipccreports/assessmentsreports.htm

[36] Olivier J, Janssens-Maenhout G, Peters J. Trends in global CO2 emissions: 2012 report. EUR 25388 EN. PBL Netherlands Environmental Assessment Agency, Publications Office of the European Union 2012; JRC72721.

[37] Anomohanran O. Estimating the Greenhouse gas emission from petroleum product combustion in Nigeria. Journal of Applied sciences 2011; 11 (17): 3209-3214.