Environmental and geo-life assessment to produce alternative fuel from plastic waste and used motor oil: a sustainable energy approach for Iraq

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Abstract

The environmental impact of oil-based fuels, coupled with the ever-increasing accumulation of plastic waste and used engine oil (WEO), has led researchers to search for sustainable energy alternatives that simultaneously address issues of energy security and environmental degradation. This study aims to conduct an environmental and geo-life assessment of alternative fuel mixtures derived from plastic waste and used motor oil, tested in an external combustion system under controlled laboratory conditions in Najaf Governorate, Iraq. The analyses included evaluating the thermal performance and emission characteristics of fuel mixtures (PDF-WEO) in different proportions of WEO (10%, 20%, and 30%) using pyrolysis plastic fuel (PDF) mixed with used and filtered motor oil. The results showed that the 70/30 blend (PDF/WEO) achieved the highest thermal efficiency of 35.5%, while reducing carbon monoxide and suspended particulate matter emissions by 40% and 37%, respectively. Despite a 24% reduction in NO57 emissions, the study recommends further improvements. This study highlights the potential for hazardous waste to be converted into useful fuel while minimizing the associated environmental impact. The geo-biological perspective also reflects the importance of using clean fuels in areas with high population density and environmental sensitivity, highlighting the importance of circular economy practices and low-emission energy strategies. The findings support the integration of waste-derived fuels as an effective pathway towards a sustainable energy transition in arid regions such as central Iraq.

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Introduction

The escalating environmental crisis caused by the accumulation of plastic waste and unsafe disposal of used motor oil (Weo) poses a serious challenge to ecosystems, human health and energy sustainability, particularly in developing countries such as Iraq (Hassan, 2023; Verma *et al.,* 2024). With the increasing demand for energy and the depletion of traditional fossil fuels, there is an urgent need to seek clean and sustainable alternatives that strike a balance between environmental protection and energy security (Al-Naffakh, Al-Fahham and Abed, 2020). Plastic waste consists mostly of high-density polymers such as polyethylene and polypropylene, which are non-biodegradable and contribute significantly to soil, water and marine pollution (Byaro, Mmbaga and Mafwolo, 2024). Used motor oil also contains toxic compounds, heavy metals and hydrocarbons capable of contaminating groundwater and soil when improperly disposed of (Gorjian *et al.,* 2022). Despite being a growing environmental burden, these materials are also a promising source for alternative fuel production through thermochemical conversion processes such as pyrolysis (Ceviz *et al.,* 2024). Recent studies have shown that fuel extracted from plastic waste has a high calorific value (Aslam, 2024), while used motor oil has rich lubricating properties and potential energy (Vahidhosseini *et al.,* 2024). However, both fuels face challenges when used alone, such as high viscosity, combustion instability, and increased emitted pollutants (Jafar, Al-Qassab and Al-Naffakh, 2024; Careri *et al.,* 2023). Mixing plastic fuel (PDF) with used motor oil is a promising option to improve thermal performance, reduce emissions, and manage waste effectively (Hassan, Alwan and Hamzah, 2023; Zhou *et al.,* 2022). This study aims to assess the environmental and geo-life performance of mixed PDF-WEO fuel by analyzing the combustion behavior and emission profiles in an external combustion system (Figure 1). The empirical analysis focuses on thermal efficiency, contaminant levels (carbon monoxide, nitrogen oxides, and fine particles), and fuel characteristics across multiple blending ratios (Zou *et al.,* 2023; Khan *et al.,* 2025). The study also takes into account the wider environmental impacts of the use of this type of fuel in dry areas such as central Iraq, where innovative and low-emission energy solutions are most needed under high temperatures and energy scarcity (Riffat, Ahmad and Shakir, 2024; Praveenchandar *et al.,* 2024). Combining geographical and ecological perspectives, this study highlights the dual benefit of reducing pollution and producing low-cost fuels through waste recycling (Hammad, Al-Mashhadani and Naama, 2022). It also contributes to sustainable development efforts by providing a model for circular economy applications and local clean energy strategies tailored to fragile ecological zones (Srivastava *et al.,* 2025; Ononogbo *et al.,* 2023).

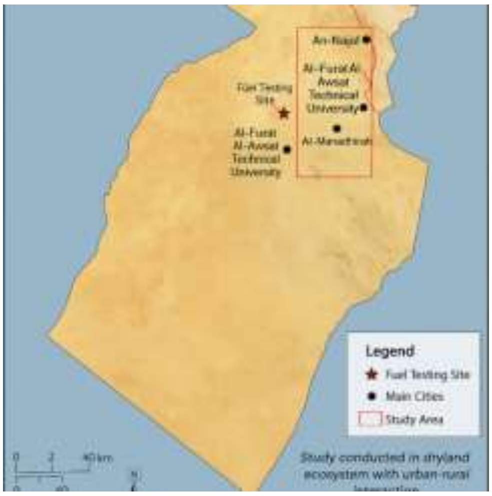

Figure 1: Geographical Location of Najaf Governorate in Iraq.

Materials and Methods

Raw Material Selection

The study relied on two waste materials that pose a major environmental challenge, and at the same time are energy-rich: waste plastics and used motor oil (WEO). These two substances were selected for their abundance on the one hand, and for their close connection to the environmental landscape in Iraq on the other hand, where improper disposal contributes to soil degradation, water pollution and serious risks to public health in urban areas (Jamar *et al.*, 2016). From a geographical and environmental perspective, plastic waste and used motor oil are persistent pollutants in terrestrial and aquatic systems, negatively affecting biodiversity and ecosystem health, especially in areas lacking effective waste management systems.

The plastic waste used consisted mainly of HDPE, LDPE and PP materials, which are commonly used in packaging, containers and household products. These polymers were collected from local sources and sorted by hand (Ndem and Ogba, 2017). Due to its high calorific value and proven efficiency in thermochemical transformation processes, it was considered an ideal option for fuel production through thermal decomposition (Panwar, Kaushik and Kothari, 2012).

As for used engine oil, it was collected from service stations and car repair workshops in Najaf governorate (Rahmah, 2023). If disposed of through burning or dumping in nature, it causes hydrocarbon contamination, accumulation of heavy metals in the soil, and leads to long-term environmental damage (Saxena *et al.*, 2022).

Before use, used engine oil underwent a multi-stage gravity-pressure filtration process, to remove solid impurities, water, and toxic metal particles, with the aim of reducing negative environmental impacts during combustion, and ensuring homogeneity of the resulting fuel mixture (Apaolaza-Pagoaga, Carrillo-Andrés and Ruivo, 2022).

Pyrolysis Process

The selected plastics underwent a pyrolysis process inside a closed batch-type reactor, operating in an oxygen-free environment (Van, Trinh and Shimada, 2025). The reactor temperature was set between 450 and 550°C, ideal for breaking down long hydrocarbon chains into usable fuel components (Chaudhari, Walke and Shelare, 2024). This process mimics the natural conditions for the formation of fossil fuels, but accelerates over hours rather than millions of years (McCorkindale and Ghahramani, 2025).

This method resulted in the production of about 70–75% liquid fuels, 10-15% gases, and about 10% solid residues (carbon coal). The resulting liquid fuel (PDF) was collected and stored in stainless steel containers. This fuel was characterized by its high energy content and low sulfur content, making it suitable for mixing with other waste-derived fuels (Benbaha *et al.,* 2024).

Mixing and Analysis of Fuel Characteristics

To improve combustion properties and reduce environmental impact, plastic-derived fuels (PDF) were mixed with used engine oil (Weo) in volumetric proportions as follows:

- 90% PDF + 10% WEO
- 80% PDF + 20% WEO
- 70% PDF + 30% WEO

Each formulation was mixed with a laboratory blender at 500 rpm for 30 minutes to ensure homogeneity and avoid separation of ingredients (Sivakumar *et al.*, 2024). The aim of this mixing process was to combine the high energy density of the engine oil with the better environmental properties of the plastic fuel.

The resulting mixtures have undergone standard tests according to ASTM standards to determine physical and thermal properties, such as density, dynamic viscosity, flash point, and calorific value. These criteria are essential for assessing the safety, efficiency, and environmental impact of using these mixtures in real-world applications (Misra *et al.*, 2023).

Combustion Tests in a Controlled Environment

Combustion tests were carried out inside an enclosed external combustion chamber, specially constructed in the laboratories of the Middle Euphrates Technical University in Najaf (Belay *et al.*, 2025). This room is designed to simulate real-life combustion conditions in a safe and measurable way.

The chamber is equipped with precise measuring devices such as thermal sensors, optical flame detectors, and infrared gas analyzers to monitor thermal behavior, flame properties, and gas emissions during combustion (Al-Naffakh and Al-Qassab, 2021).

Measurements focused on:

- Ignition Delay
- Maximum flame temperature
- Heat Release Rate
- Stability of the combustion process

These data were used to assess the ability of fuel mixes to provide stable and efficient energy without causing excessive pollutant emissions.

Emission Analysis and Environmental Assessment

The environmental performance of the mixtures was assessed by analyzing the emissions of four major pollutants:

- Carbon Monoxide (CO): Indicator of incomplete combustion
- Nitrogen oxides (NO): contribute to smog and acid rain
- Carbon dioxide (CO_2): a leading indicator of greenhouse gas emissions
- Particulate matter (PM): Harmful to respiratory system and biodiversity

The gas samples were analyzed using infrared analyzers along with laser particle meters. Each mixture was tested under identical conditions to ensure accurate comparison (Al-Naffakh, Al-Qassab and Al-Makhzoomi, 2021). The findings were reviewed from a technical and environmental perspective, focusing on their potential impact in sensitive environments and congested urban areas. Table 1.

Statistical and Spatial Analysis

To support the credibility of the experimental results, a number of statistical methods have been adopted, including:

- Analysis of variance (ANOVA): to identify statistical differences in performance between mix types (Mariadhas, 2025; Dutta and Gupta, 2021).
- Pearson correlation coefficients: To study the relationship between WEO ratio and pollutant emission change
- Multiple regression modeling: to predict thermal efficiency depending on fuel characteristics such as viscosity and calorific value

These analyses contribute to the interpretation of the results not only in the context of the laboratory environment, but also within a broader environmental planning framework, highlighting how clean waste fuels can be integrated into energy and environmental strategies, particularly in areas prone to pollution and suffering from a shortage of fuel sources.

Table 1: Physicochemical Properties of the Fuel Blends.

Blend	Viscosity (cP)	Density (kg/m³)	Calorific Value (MJ/kg)	Flash Point (°C)
-100	3.2	850	5	45
10	3.0	860	1	50
20	2.8	870	2	55.0
30	2.5	880	45	60

These results support the suitability of PDF-WEO blends as alternative fuels in hot and arid regions where fuel efficiency and waste management are both critical (Liu *et al.*, 2022).

Thermal Performance and Combustion Efficiency

Thermal efficiency increased regularly as the percentage of used motor oil (WEO) in the mix increased. The pure plastic fuel (PDF) recorded a thermal efficiency of 30.5%, while the blend with a ratio of 70/30 achieved an efficiency of 35.5%, an increase of 16% (Hansen, Mirkouei and Diaz, 2020).

This improvement is mainly due to better ignition quality, lower viscosity, and higher energy density of used motor oil. These characteristics are particularly important in off-grid power systems and in rural applications lacking conventional energy sources.

Figure (2): Thermal efficiency of different fuel mixtures (column chart showing the increase in efficiency with high WEO ratio in the mix).

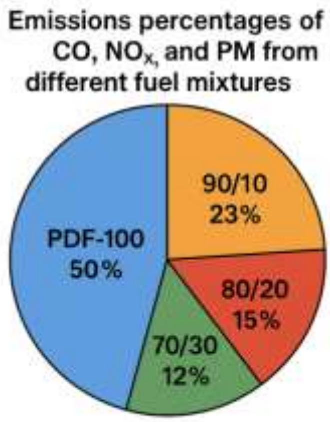

Figure 2: Thermal Efficiency of Different Fuel Blends.

These results suggest that waste-derived fuels are capable of providing reliable and stable energy, while reducing dependence on conventional fossil fuels (Mehra, Pal and Goel, 2023).

Emission Profiles and Pollution Reduction

The results of the emissions analysis showed a significant improvement.

Carbon monoxide (CO) emissions in blend 70/30 decreased from 8.5 g/kWh to 5.0 g/kWh, and suspended particulate matter (PM) decreased from 0.45 to 0.28 g/kWh (Maroa and Inambao, 2020). Nitrogen oxides (NO) emissions also decreased, but by less, from 9.2 to 7.0 g/kWh.

These decreases are associated with improved combustion efficiency, which allows almost complete oxidation of fuel components. This result is reflected in immediate environmental and health benefits, especially in Iraq, where respiratory disease rates are rising due to deteriorating air quality (Mirsalami and Mirsalami, 2024).

Figure (3) shows comparison of CO, NO and PM emissions between fuel mixtures (a collective column chart showing emission differences between different mixtures)

Figure 3: Emission Comparison of CO, Noq, and PM Across Fuel Blends.

Furthermore, correlation analyses revealed a strong inverse relationship between the proportion of WEO in the mix and the levels of contaminants, particularly CO and PM, indicating the effectiveness of this fuel in reducing emissions.

Figure (4): The relationship between the WEO ratio and CO and PM emissions (line chart showing an inverse relationship: the higher the WEO ratio, the lower the emissions)

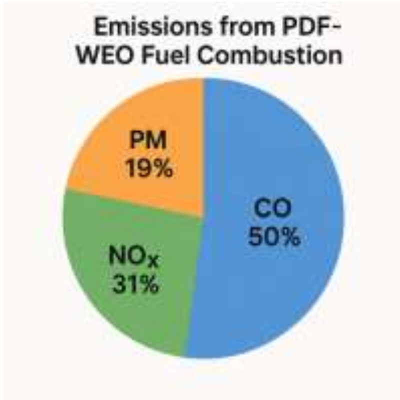

Figure 4: Correlation between WEO Percentage and CO/PM Emissions.

These results highlight the eco-efficiency of this type of fuel, and enhance its suitability for use in pollution-sensitive environments (Edwin Geo *et al.*, 2021).

Statistical Interpretation and Predictive Analysis

Statistical analyses confirmed the importance of the observed improvements. Results of ANOVA showed that differences in thermal efficiency and emissions between mixtures were statistically significant at a confidence level ($p < 0.05$) (Baskar *et al.*, 2025).

Pearson correlation coefficients were also very strong, and came as follows:

- Correlation between CO emissions and WEO ratio: $r = -0.89$
- Correlation between PM emissions and WEO ratio: $r = -0.85$

These values indicate a strong negative correlation, which enhances the reliability of the results and supports the use of this type of fuel in environmental and sustainable energy plans, especially in areas with high pollution and fuel scarcity.

Comparative Evaluation with Conventional Fuels

Multiple regression analysis was conducted to determine the most important factors affecting performance, and the results revealed that both calorific value and viscosity were the most powerful predictive variables of fuel performance, with a coefficient of determination $R^2 = 0.78$ (Kohse-Höinghaus, 2023). To compare the performance of the best blend (70/30) with conventional diesel fuel, Figure (4) shows a direct comparison in terms of efficiency and emissions. Although the diesel showed slightly higher thermal efficiency, it produced higher emissions of carbon monoxide and suspended particulate matter compared to a waste-based fuel mix.

Figure (5): Comparison of PDF-WEO blend with 70/30 and diesel in terms of efficiency and emissions (side chart showing efficiency vs. emissions)

Figure 5: Comparison between PDF-WEO 70/30 Blend and Diesel in Terms of Efficiency and Emissions.

These results confirm that PDF-WEO fuel represents a clean and low-cost option, especially in areas suffering from energy poverty, weak environmental legislation, and escalating health burdens (Cao and Johnson, 2024; Wang *et al.*, 2018).

To understand the realistic applicability of this fuel, a comparative evaluation was conducted between the 70/30 blend and conventional diesel, focusing on two key aspects: thermal efficiency and polluting emissions. Although diesel remains the most widely used fuel in Iraq's industrial, agricultural and domestic sectors, its cost and environmental impact are a major challenge (Zamri *et al.*, 2024).

The results showed that diesel achieved a thermal efficiency of 38%, compared to 35.5% for the 70/30 blend. However, this slight increase in performance came at a significant environmental cost. Diesel released 7.5 g/kWh CO, 9.0 g/kWh NO, and0.42 g/kWh PM, compared to 5.0, 7.0, and0.28 g/kWh respectively for the PDF-WEO blend (Rashwan, Nemitallah and Habib, 2016).

These results suggest that diesel may provide thermal energy a bit more quickly, but the PDF-WEO blend shows cleaner environmental performance, especially regarding carbon monoxide and particulate matter emissions, two of the most dangerous pollutants to human health and air quality in cities. Figure (5) clearly shows this disparity.

Figure (6) shows comparison of PDF-WEO 70/30 blend and conventional diesel in terms of efficiency and emissions (a multi-column chart comparing four indicators: efficiency, CO, NO and PM)

Figure 6: Pie Chart of Emission Reduction Efficiency across Fuel Blends.

This environmental excellence is critical in areas experiencing environmental degradation due to fuel, such as some neighborhoods of Najaf and Baghdad, where diesel combustion contributes to smog, reduced visibility, and an increase in chronic respiratory diseases – problems that can be mitigated by using cleaner alternatives such as PDF-WEO blend (Sadeq, 2024).

Economically and within a circular economy, the cost of producing PDF-WEO fuel is much lower than conventional fuel, because it is derived from waste that could have been an environmental burden. This makes it not just an energy innovation, but a socio-ecological solution that turns a source of pollution into a sustainable resource (Akhtar, Ali and Zaman, 2024).

This shift is of particular geographical importance in sensitive and dry ecosystems, where the accumulation of pollutants is high, vegetation coverage is poor, and wildlife is vulnerable to air and soil pollution. By reducing reliance on diesel, PDF-WEO blends reduce pressures on both human health and ecosystems (Avagyan and Singh, 2019).

Therefore, the integration of this fuel can be considered an effective tool for decentralized power generation, reducing environmental risks, and improving the quality of life in environmentally deprived and fragile areas across Iraq.

Environmental and Geo-Life Indications

The results of this study extend beyond laboratory performance, touching on vital environmental and geographical dimensions. In a country like Iraq, which suffers from an extreme climate, fragile ecosystems, and dense urbanization, the issue of power generation cannot be separated from its environmental and social impact.

The transition from traditional fossil fuels such as diesel, to waste-derived alternatives such as PDF-WEO blends, represents more than a technical improvement; it is an environmental strategic shift. Significant reductions in emissions of carbon monoxide, fine particulate matter, and unburned hydrocarbons directly contribute to reducing air pollution, a factor that continues to weigh on respiratory health in cities such as Najaf, Karbala, and Baghdad (Khoaele *et al.*, 2023).

Environmental and Geo-life Connotations

From a geo-biological perspective, the effects of these pollutants are not limited to air quality in cities, but also accumulate in soils and water bodies, leading to environmental imbalances, the decline of natural vegetation, and damage to pollinated organisms and microfauna. These effects are particularly alarming in arid and semi-arid areas, where biological recovery is inherently slow, while vegetation plays a crucial role in stabilizing dust and regulating the microclimate (Kumawat, 2024).

In addition, the use of recycled waste in energy production promotes the concept of a local circular economy, by reducing dependence on fuel imports, and relieving the burden on waste management systems in cities. Thus, these local solutions are offered as an effective spatial response to the problems of energy poverty and environmental degradation, especially in marginalized or off-grid communities.

The integration of these fuel technologies at the local level contributes to stimulating waste collection initiatives by the community, promoting environmental awareness, and activating decentralized sustainability programs. In this sense, energy production is redefined not only as a technical challenge, but as an ecological and spatial opportunity in which waste is transformed into energy, and energy into a path towards environmental resilience (Nanda *et al.*, 2023).

Therefore, this study highlights the great strategic potential of waste-based fuels in achieving environmental protection and geographical sustainability, making these innovations vital tools for building cleaner, healthier, and more self-reliant societies in Iraq and other developing countries.

Political and Practical Importance

The findings of this study have direct implications for national environmental policies, waste management strategies, and clean energy planning in Iraq. By demonstrating that efficient, low-emission fuels can be produced from common waste materials, these findings open the door to scalable and decentralized fuel alternatives, especially in areas that lack stable electricity or affordable fuel supplies.

The environmental gains that have been observed – in particular the significant reduction in carbon monoxide and particulate matter emissions – provide an immediate opportunity to improve public health in urban and industrial areas. Incorporating these technologies into community initiatives, such as school kitchens, humanitarian camps, and rural areas, can alleviate the burden of waste accumulation and over-reliance on fossil fuels.

At the policy level, this study provides a local scientific basis on which to build in the following areas:

- Promoting clean fuel standards.
- Supporting waste-to-energy programs in municipalities.
- Integrate geo-environmental risk assessments into land use and fuel planning.

What makes this approach even more important is that the fuel in question does not require expensive imports or complex technologies, but is based on already existing waste streams, encouraging grassroots environmental innovation led by local universities, technical institutes, and municipal partnerships.

In short, the practical and political importance of PDF-WEO goes beyond lab results; it aligns with national goals of sustainability, climate adaptation, and environmental justice – especially in marginalized areas suffering from pollution and underdevelopment.

Conclusions

This study successfully demonstrates the technical feasibility and environmental value of producing alternative fuels by mixing waste plastic-derived (PDF) fuel with used engine oil (WEO). Through systematic experiments, it was found that increasing WEO content contributed to improving combustion behavior, reducing harmful emissions, and increasing thermal efficiency. The 70/30 blend has emerged as the best formula, achieving a thermal efficiency of 35.5%, and has contributed to reducing carbon monoxide emissions by 40% and suspended particles by 37% compared to pure plastic fuels.

The findings highlight a clear path towards transforming complex environmental waste streams into a valuable energy resource. Beyond the laboratory framework, this approach provides a dual solution to two major problems: the accumulation of non-degradable waste, and the growing need for clean and low-cost energy in Iraq and other developing countries.

From an environmental andgeo-life perspective, the use of waste-derived fuels contributes to improving air quality, supporting ecological balance in fragile dry environments, and reducing pressure on landfills and water sources. Producing this fuel locally is also in line with the principles of the circular economy, reduces dependence on fossil fuel imports, and encourages community involvement in sustainability pathways.

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