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Transforming Plastic Waste into Energy: Pyrolysis Applications and Sustainability Prospects in Sub-Saharan Africa

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ABSTRACT

This study reviews the applications of pyrolysis in Sub-Saharan Africa, emphasizing the environmental sustainability, resource and energy recovery potential, and technical flexibility of pyrolysis. A systematic literature review approach was employed, utilizing secondary data from 24 articles sourced from major academic databases published between 2015 and 2025. Articles were identified using Boolean keyword combinations related to pyrolysis, plastic waste, urban settings, and Sub-Saharan Africa, and screened based on predefined inclusion and exclusion criteria. The findings reveal that pyrolysis offers significant greenhouse gas mitigation benefits, with several studies reporting net negative emissions and notable reductions in global warming potential compared with landfilling and incineration, as well as conserving virgin resources. This technology also demonstrates strong waste-to-wealth potential through the production of high-calorific-value liquid fuels, syngas, and value-added byproducts such as biochar and carbon nanotubes. Furthermore, the findings indicate that pyrolysis is highly tolerant of contaminated, mixed, and low-quality plastics unsuitable for mechanical recycling, with successful implementation at laboratory, pilot, and simulated commercial scales in Nigeria, Ghana, Uganda, Ethiopia, and South Africa, and Sudan. Overall, this review demonstrates that pyrolysis holds significant potential as a scalable and flexible waste-to-energy solution for managing heterogeneous plastic waste in sub-Saharan Africa.

Keywords**:** Plastic waste management, Waste-to-energy, Sub-Saharan Africa, Circular economy, Chemical recycling, Environmental sustainability.

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1. INTRODUCTION

Plastic waste pollution has emerged as one of the most pressing environmental and public health challenges in sub-Saharan Africa, where approximately 80% of all plastic products are mismanaged as waste [33], [37], [40]. This crisis is driven by rapid urbanization, explosive population growth, and widespread consumption of low-cost single-use plastics that currently dominate the regional packaging sector [9], [40]. Throughout the region, inadequate collection systems, limited source separation, and insufficient recycling infrastructure have led to significant volumes of plastic waste being disposed of through open dumping, burning, and uncontrolled landfill disposal. This has resulted in severe environmental degradation, greenhouse gas emissions, and public health risks [30], [34]. Simultaneously, Sub-Saharan Africa faces persistent energy deficits, especially in urban and peri-urban areas, where reliance on fossil fuels and traditional biomass continues to hinder climate mitigation and sustainable development efforts [18], [39]. These challenges reflect a wider global deficit in modern energy access, with more than 730 million people lacking electricity and nearly 2.0 billion people relying on traditional biomass, primarily firewood and charcoal, for cooking and heating [22]. In most countries in the Sub-Saharan region, access to clean energy remains below 80%, perpetuating the reliance on inefficient and carbon-intensive fuels [21], [22]. These challenges have intensified the demand for accessible, low-carbon, and waste-derived energy sources that can complement conventional renewable technologies such as solar and hydropower.

The overlapping crises of plastic pollution and energy insecurity have heightened interest in waste-to-energy technology as an integrated solution. These technologies contribute to resource recovery and energy generation; however, they are often constrained in sub-Saharan Africa by weak waste segregation systems, high moisture and contamination levels, limited capital investment, and stringent technological requirements [28]. Other techniques, such as mechanical recycling, are restricted to clean and single-polymer streams, whereas incineration and gasification require high capital costs, advanced emission control systems, and stable waste supplies [25], [20]. To address these challenges, pyrolysis has gained attention as a promising chemical recycling and waste-to-energy pathway, capable of converting heterogeneous plastic waste into valuable energy carriers and material products under oxygen-deficient conditions. Unlike conventional recycling and high-temperature combustion-based technologies, pyrolysis can tolerate mixed, contaminated, and low-grade plastics that dominate municipal waste streams in sub-Saharan Africa. However, debates continue regarding the environmental performance, economic feasibility, and technical scalability of pyrolysis in developing regions, particularly regarding emission control, feedstock variability, and system reliability.

This presents a critical and underexplored context for plastic waste pyrolysis in sub-Saharan regions because of the distinctive intersection of high plastic leakage, rising energy demand, limited waste management infrastructure, and constrained financial and technical capacities. These waste management and resource recovery constraints create both a necessity and opportunity for adaptable, low-cost, and decentralized technologies, such as pyrolysis, to address waste and energy challenges. This systematic review examines the application of plastic waste pyrolysis in Sub-Saharan African countries, including Nigeria, Ghana, Uganda, South Africa, and Ethiopia. This review focuses on environmental sustainability, resource and energy recovery, and technical flexibility in the utilization of diverse local feedstocks for biogas production. These parameters are essential because environmental sustainability determines emission reduction and pollution control performance, resource and energy recovery addresses the region's energy deficits, and technical flexibility enables the effective treatment of heterogeneous and contaminated plastic-waste streams.

While existing studies indicate that pyrolysis can reduce emissions and generate valuable fuels and materials, current evidence in Sub-Saharan Africa remains scattered, context-specific, and limited in its assessment of system performance across diverse feedstocks and operating conditions. This review addresses this gap by synthesizing regional evidence on the environmental, energy, and technical performance of plastic waste pyrolysis systems. Thus, this review evaluates the greenhouse gas mitigation and pollution control potential of pyrolysis, its capacity to convert plastic waste into high-value fuels and materials, and its adaptability to heterogeneous feedstocks through co-pyrolysis and decentralized experimental, pilot, and simulated systems in the region.

2. MATERIALS AND METHODS

2.1. Review Design

This study adopts an integrated critical literature review to examine the application of pyrolysis technology as a waste-to-energy solution for managing heterogeneous urban plastic waste in Sub-Saharan Africa. This review combines systematic search procedures with structured thematic synthesis to evaluate the technological performance, operational feasibility, and broader role of pyrolysis within regional waste management systems.

2.2. Inclusion and Exclusion Criteria

The review included peer-reviewed studies that examined the pyrolysis of plastic waste in Sub-Saharan Africa, focusing on experimental, pilot-scale, and techno-economic assessments of the technology. Eligible studies addressed aspects such as process efficiency, feedstock composition, product yields (oil, gas, and char), operational conditions, and the economic viability of pyrolysis for plastic waste management. Only publications written in English and published between January 2015 and March 2025 were included. This time frame corresponds to the Sustainable Development Goals (SDGs) implementation period (2015-2030), during which waste-to-energy technologies have received increased attention as potential solutions to urban waste challenges in developing regions. Studies conducted outside sub-Saharan Africa were excluded unless their findings demonstrated clear applicability to the regional context. In addition, studies focusing solely on mechanical recycling, composting, or other non-thermal treatment technologies and publications outside the specified time period were excluded.

2.3. Search Strategy

A comprehensive literature search was conducted across multiple academic databases, including Google Scholar, Elsevier, BASE, Research4Life, Scopus, and Web of Science. These databases were selected because of their extensive coverage of peer-reviewed scientific literature on environmental engineering, waste management, and energy recovery technology. The search strategy used Boolean operators combined with keywords relevant to pyrolysis and plastic waste management in urban environments. Key search terms included "pyrolysis," "plastic waste," "urban," and "Sub-Saharan Africa (SSA)," together with modifiers such as "management" and "treatment." The search string applied in the Web of Science was structured as follows: TS = (pyrolysis AND "plastic waste" AND urban AND ("Sub-Saharan Africa" OR "SSA") AND (management OR treatment)). Similar keyword combinations were adapted for other databases to ensure the consistent retrieval of relevant studies.

2.4. Screening and Selection

The screening and selection processes followed the PRISMA-informed procedures. The initial search identified 2,191 records across the selected databases. After removing 418 duplicate records, 1,773 studies remained for title and abstract screening. During this stage, studies that did not meet the inclusion criteria, such as those unrelated to plastic waste pyrolysis, those focusing on different waste treatment technologies, or those conducted outside sub-Saharan Africa without contextual relevance, were excluded from the review. After this screening process, 1,749 records were removed. The remaining studies were assessed for eligibility through full-text evaluation, resulting in 24 studies being included in the final analysis. The detailed flow of records from identification to inclusion is shown in Figure 1.

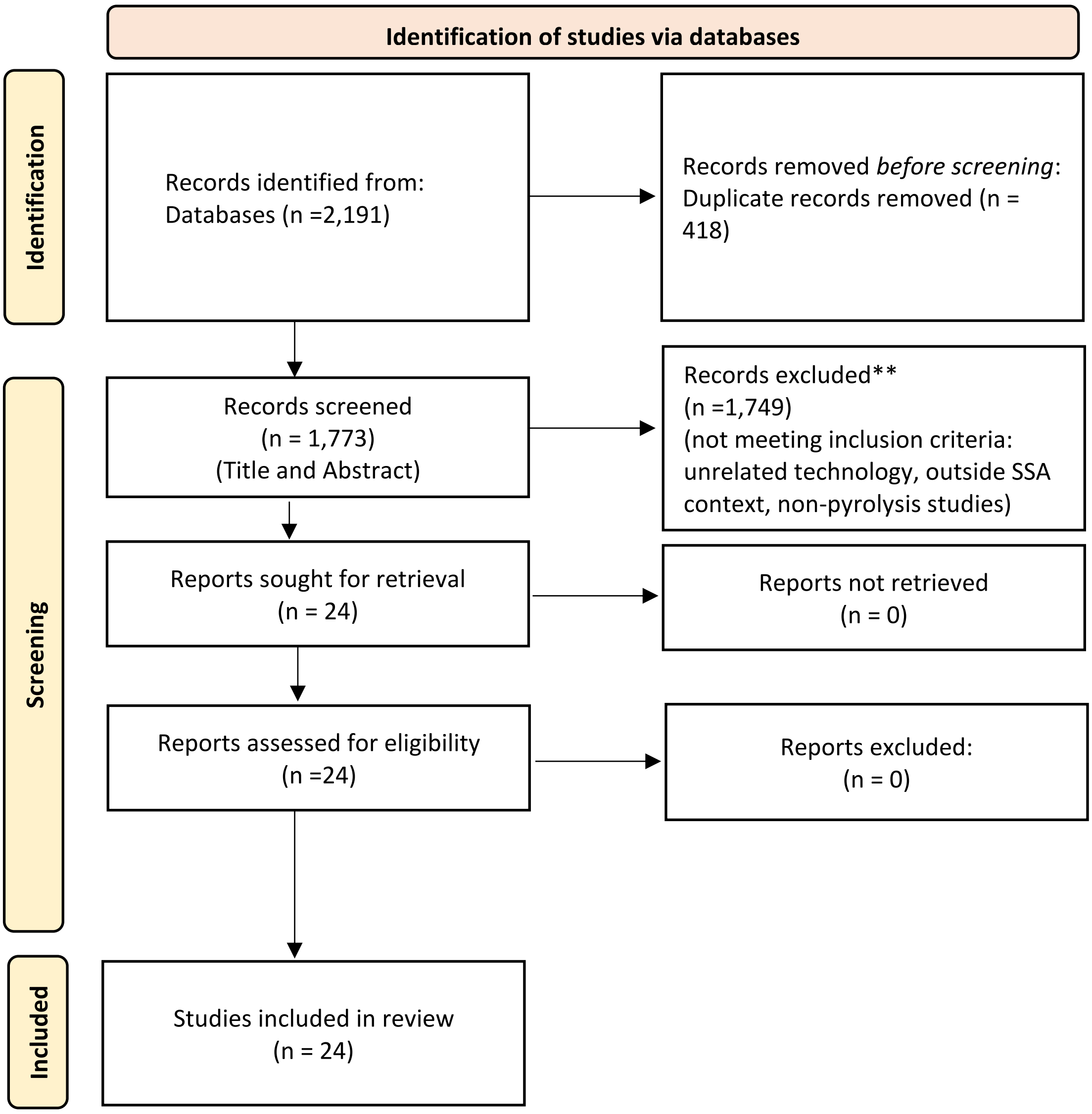

Figure 1. PRISMA Flow Diagram for Literature Screening Process.

3. RESULTS AND DISCUSSION

3.1. Environmental Sustainability

3.1.1. Climate Mitigation Benefits of Plastic Pyrolysis

Research from sub-Saharan Africa highlights that pyrolysis-based waste-to-energy systems offer significant climate-mitigation benefits by simultaneously reducing landfill emissions and replacing fossil-based energy sources. Unlike traditional waste disposal methods, pyrolysis transforms carbon-rich waste into usable fuels, providing both waste management and energy system decarbonization advantages within a single technological framework. Studies in the sub-Saharan region have shown a reduction in greenhouse gas (GHG) emissions through pyrolysis integration. In Ghana, [3] demonstrated that a hybrid waste-to-energy system incorporating pyrolysis reduced emissions by 310% compared to landfilling, resulting in carbon savings of 3.52 tCO_2-eq per ton of waste treated. Over a 20-year operational period, this system is projected to prevent approximately 1.28 million tons of CO_2 by processing 365,000 tons of municipal solid waste annually. Similarly, [17] estimated that household waste pyrolysis in Ethiopia could reduce emissions by 25,303 tCO_2-eq per year, equivalent to the carbon sequestration of over 650,000 tree seedlings over ten years, underscoring its importance in rapidly urbanizing areas where nature-based solutions alone are insufficient. The high organic content and moisture levels in municipal solid waste in urbanized cities, such as Dar es Salaam in Tanzania, pose challenges for efficient pyrolysis and the achievement of similar climate benefits. However, the implementation of feedstock pretreatment and segregation systems can improve the efficiency of waste management [26].

Beyond municipal waste, the pyrolysis of plastic waste demonstrates impressive climate performance. In Sudan, [31] modelled a pyrolysis-based power plant processing 37.5 $t\ h^{-1}$ of low-density polyethylene and discovered net-negative emissions of 33-38 tCO_2 per ton of plastic processed, marking an approximately 80% reduction compared to landfill disposal. Similar findings were reported by [3], who observed that the Ghanaian waste-to-energy plant achieved net-negative emissions of 2.38 tCO_2-eq per functional unit, with pyrolysis contributing 2.30 tCO_2-eq. The consistency of the results across different countries indicates that the climate benefits of pyrolysis are not site-specific but are inherently linked to its capacity to prevent methane emissions from waste and reduce the use of fossil energy. Importantly, these climate advantages extend beyond the waste treatment phase to the downstream energy applications. Pyrolysis-derived diesel exhibits a significantly lower carbon footprint than conventional fossil-derived diesels. [8] reported a global warming potential of 431.6 $kgCO_2$-eq per ton for pyrolysis diesel, compared to 645.2 $kgCO_2$-eq per ton for fossil diesel, suggesting that waste-derived fuels can further enhance the emission reductions achieved during waste-to-energy conversion. This benefit is particularly relevant to Tanzania, given the country's heavy reliance on imported petroleum fuels, such as petrol and diesel, in the transport sector and its dependence on charcoal as a cooking fuel [11], [15].

Collectively, evidence from Ghana, Ethiopia, and Sudan illustrates that incorporating pyrolysis into waste management and energy systems offers a strong pathway for reducing greenhouse gas emissions in Sub-Saharan Africa. By curbing landfill emissions, replacing fossil fuels, and generating low-carbon liquid fuels, pyrolysis can achieve net-negative or nearly neutral carbon outcomes while addressing the escalating waste challenges in the region. This dual benefit for climate and waste management positions pyrolysis as a vital technology for meeting both environmental and energy transition objectives.

3.1.2. Emission Reduction and Air Quality Benefits of Plastic Pyrolysis

Pyrolysis is increasingly recognized as a cleaner alternative for waste management compared to conventional methods such as open burning, incineration, and landfilling, owing to its capacity to significantly reduce the formation and release of hazardous airborne pollutants. The primary mechanism involves the thermal decomposition of waste in an oxygen-limited or oxygen-free environment at temperatures ranging from 350-550 °C [10], [2]. This operational feature effectively prevents the generation of combustion-related pollutants, including nitrogen oxides (NO_x), carbon monoxide (CO), sulfur oxides (SO_x), dioxins, and furans [14], [5]. In contrast, uncontrolled open burning and incineration result in high concentrations of these toxic pollutants, which have direct adverse effects on human health, particularly in densely populated urban areas. In cities such as Dar es Salaam, where informal settlements are often situated near dumpsites and unregulated waste disposal is prevalent, the implementation of pyrolysis provides a means to reduce pollution exposure, mitigate health risks associated with municipal solid waste mismanagement, and support ongoing efforts to enhance urban environmental conditions [23], [29].

In addition to emission control, the byproducts of pyrolysis contribute to environmental benefits. Pyrolytic oil has a very low sulfur content (0.019%), thereby minimizing its potential contribution to SO_x emissions, whereas the solid biochar residue can be activated for use in air purification and pollutant adsorption [35]. Conversely, conventional disposal practices, such as incineration and open burning, continue to be significant sources of NO_x, CO, SO_x, and highly toxic dioxins, thereby degrading air quality and posing long-term public health risks [5]. Avoiding these practices through the adoption of pyrolysis presents a critical opportunity to limit toxic and carcinogenic emissions while converting waste into valuable energy and material [10]. In general, these attributes advocate for the integration of pyrolysis into urban waste management systems as an effective strategy for reducing hazardous emissions, improving air quality, and safeguarding public health in rapidly urbanizing communities near dumpsites.

3.1.3. Resource Conservation and Energy Substitution via Plastic Pyrolysis

The reviewed literature suggests that pyrolysis aids in conserving virgin resources by replacing fossil-based fuels and materials with products derived from waste, thereby reducing the overall demand for resource extraction and processing. This conservation is achieved by producing high-value fuels that substitute virgin fossil fuels, which have significant environmental impacts. [41] supported the assertion that pyrolysis technology is environmentally friendly, as its products, particularly liquid fuels (oils), replace conventional diesel fuels, which incur higher costs and greater cumulative exergetic consumption. High cumulative exergy consumption indicates substantial amounts of virgin resources, energy inputs, and refining processes required for conventional fuel production, highlighting the comparative efficiency of pyrolysis-based alternatives in terms of exergy. An extended exergy analysis further confirmed the resource conservation benefits of pyrolysis. [6] found that pyrolysis avoids 11,303 MJ of exergy per ton of plastic waste processed, making it one of the most efficient methods for recovering the embedded energy and material value in plastic waste. While incorporating plastic into asphalt achieves higher exergy savings, pyrolysis uniquely produces liquid fuels and chemical feedstocks that can replace imported petroleum products, thereby directly reducing the demand for virgin fossil resources in the energy and industrial sectors. This functional advantage makes pyrolysis particularly relevant in economies such as Tanzania, which heavily relies on fuel importation. The country depends on imported petroleum fuels for transport, power generation, and industry, exposing its economy to price volatility and foreign exchange pressure [38].

Evidence from the Ashanti Region of Ghana further highlights the energy recovery potential of pyrolysis within an integrated circular system. A hybrid waste-to-energy plant that combines solar PV, anaerobic digestion, and pyrolysis has been shown to convert plastic waste into bio-oil for a 50-kW CHP engine, generating approximately 810 MWh of electricity annually [4], [31]. This integration underscores the strategic role of pyrolysis in enhancing the resilience, diversification, and flexibility of renewable energy systems, particularly in resource-constrained environments such as developing countries. The benefits of resource conservation are also evident in solid waste management. Research conducted in Jimma City, Ethiopia, revealed that biochar produced from slow pyrolysis at 400°C possesses favourable agronomic properties, such as a pH of 7.5 and a C/N ratio of 25.83, making it an effective soil conditioner and nutrient source for sustainable urban agriculture [17]. This indicates that pyrolysis residues can offset the use of synthetic soil amendments and fertilizers, further reducing reliance on virgin inputs. In Tanzania, where soils in many peri-urban and agricultural areas are degraded and fertilizer costs are high, the use of pyrolysis biochar could decrease dependence on imported agro-chemicals while enhancing soil productivity and conserving upstream mineral and energy resources used in fertilizer production. Collectively, these findings confirm that the application of thermal conversion processes, such as pyrolysis, not only recovers energy and materials but also conserves net resources across multiple stages of the waste management chain.

3.2. Resource and Energy Recovery

3.2.1. Plastic Pyrolysis Process Conditions and Fuel Characteristics

The reviewed literature identifies pyrolysis as a core waste-to-wealth pathway, enabling the transformation of plastic waste into marketable energy products with properties comparable to or exceeding those of conventional fossil fuels. [18] and [19] described pyrolysis as an important method for biofuel production with minimal emission and waste residue. This process involves the thermochemical conversion of plastic waste into hydrocarbon fuels or valuable materials, such as liquid oil, syngas, and residue char, in the absence of oxygen [18], [19], [35]. This thermos-conversion occurs at temperature between 300-900°C [2], [7]. Indicating a contrary finding to [35] in Uganda, who described the optimum temperature range for liquid oil production to be 340-400°C. This variation highlights the sensitivity of product yield and quality to operational parameters, particularly temperature, and underscores the importance of process optimization for maximizing liquid fuel recovery.

The pyrolytic oil generated from plastic materials can be used as a substitute for traditional liquid fuels such as diesel [10]. This oil is often referred to as pyrolysis oil, bio-oil, recycled fuel oil, or plastic-derived fuel oil (PDFO) and is characterized by physical and chemical properties similar to those of conventional fuels [6], [35]. Studies, such as [35] in Uganda, have described pyrolytic oil from decomposed high-density polyethylene as dark brownish with a mixture of kerosene, gasoline, and diesel, similar to the properties of conventional hydrocarbon fuels. These differences in appearance and composition reflect variations in the feedstock type, reactor configuration, and operating conditions, rather than the fundamental limitations of the technology. In terms of quality, plastic-derived fuel oil from materials such as low-density polyethylene (LDPE) sourced from the Kiteezi landfill in Uganda exhibited a higher lower heating value (LHV) of approximately 44.94 MJ/kg than conventional diesel oil of approximately 41.50 MJ/kg [24]. [32] reported that polyethylene, polypropylene, and polystyrene exhibit high calorific values ranging from 41.9-46.5 MJ/kg. Moreover, [7] reported that pyrolytic oil from PET plastics in Ghana had a calorific value of 44.0 MJ/kg, whereas the status in Nigeria showed a high LHV of plastics, ranging from 38.0 to 46.0 MJ/kg, which is favourable for conventional fuel in a reactor.

These findings indicate a strong convergence across studies regarding the energy density of plastic-derived fuels, suggesting that similar properties can be achieved when processing predominant plastic waste streams in Tanzania, such as polyethylene carrier bags, PET bottles, and polypropylene packaging. This indicates that the production of high-energy liquid fuels with properties similar to or superior to those of petroleum-based products positions pyrolysis as a viable pathway for converting low-value plastic waste into economically competitive resources. Therefore, by producing high-energy liquid fuels with properties similar to or exceeding those of conventional petroleum products, pyrolysis demonstrates a strong capability to transform plastic waste into economically valuable and functionally competitive resources.

3.2.2. Feedstock Influence on Resource Recovery Efficiency in Plastic Pyrolysis

The reviewed evidence demonstrates that pyrolysis is an efficient resource recovery technology capable of converting a substantial proportion of plastic waste into reusable, energy-rich products, with the recovery efficiency depending on the polymer type and process conditions. [10] described that the technology converts waste plastics into hydrocarbon fuels and demonstrated the potential to recover up to 85% of plastic waste as liquid oil (bio-oil), syngas, and char (solid residue). These reusable products are recovered from different thermoplastics, such as polyethylene terephthalate (PET), high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP), and polystyrene (PS). The PS sourced from Nigeria demonstrated the highest liquid oil yield, with a value of 97 wt% [5]. Other studies in Nigeria and Uganda reported yields of 93.3 wt% (±4.3%), 80 wt% (in batch reactors), and 71.3 wt%, confirming PS as a highly favourable feedstock for oil production [5], [24], [36]. This consistently high yield is attributed to the high volatile matter content and aromatic structure of PS, which enhance the thermal depolymerization efficiency [24]. This was followed by LDPE (from Nigeria), with a liquid oil yield ranging from 74.7 wt% to 95 wt%, with a mean yield of 80.77 wt% (±19.8%) [5], [12]. Experimental results from multiple studies in Nigeria and Uganda show high liquid oil yields from LDPE in batch pyrolysis systems, with [12], [24], and [36] reporting yields of 78.4%, 80%, and 63.7%, respectively. These outcomes suggest that the branched molecular structure of LDPE promotes effective thermal cracking, making it a robust feedstock for fuel-oriented pyrolysis applications [12]. Other thermoplastic materials, such as HDPE, also exhibit high liquid oil yields, with maximum values of approximately 80.88 wt. % and an overall mean of 80.87 wt. % (±8.7%) [5]. Studies in Uganda, such as those by [36] and [24], which involved batch reactor experiments, reported oil yields of 80 wt% and 58.7%, respectively. Meanwhile, PP yielded up to 82.12 wt. % at 500°C, with an average reported yield of 77.86 wt. % (±21%) [5]. [24] and [36] observed yields of 80.6 wt% in a batch experiment and 54.1%, respectively. These variations indicate that the reactor design, operating temperature, and residence time play critical roles in determining the recovery efficiency across polymer types.

In contrast, mixed plastic feedstocks generally yield lower liquid-oil fractions. In Nigeria, [5] reported liquid oil yields below 50 wt% when mixed plastics such as PS, PE, and PP were pyrolyzed, with an average yield of approximately 48 wt% for heterogeneous municipal plastic waste. This reduction reflects the complex thermal interactions and competing degradation pathways that arise when polymers with different decomposition temperatures and reaction mechanisms are processed. This limitation is directly relevant to the Tanzanian case, where most plastics recovered from dumpsites are poorly segregated and are dominated by mixed packaging waste from households, markets, and informal vendors. In such systems, PET bottles, polyethylene carrier bags, polypropylene food containers, and multilayer sachets are typically co-disposed, leading to feedstocks that mirror the heterogeneous compositions reported in Nigeria and Ghana. Consequently, without pre-sorting or targeted feedstock control, pyrolysis facilities in Tanzania are likely to experience similarly depressed liquid-oil yields.

Moreover, PET-rich waste streams, which are abundant in Tanzanian urban centers owing to high bottled-water and soft-drink consumption, are particularly problematic. PET typically exhibits low oil yields ranging from 23 wt% to 40 wt% [5] because its decomposition favours the formation of solid residues and non-condensable gases such as CO and CO_2 rather than liquid hydrocarbons [2], [7]. This behavior can be attributed to the oxygen-rich aromatic polyester structure of PET, which promotes decarboxylation and gas evolution during thermal degradation. Therefore, in Tanzania, effective feedstock sorting, particularly the separation of PET from polyolefins such as PE and PP, will be critical for maximizing liquid fuel yields and ensuring the techno-economic viability of plastic pyrolysis systems.

3.3. Technical Flexibility

3.3.1. Pyrolysis as a Solution for Non-Recyclable Plastic Waste Streams

The reviewed articles demonstrate that pyrolysis is suitable for managing heterogeneous, contaminated, and low-quality plastic waste streams that are incompatible with mechanical recycling. This technology is vital for managing plastics that are rejected or diverted to landfills through mechanical recycling processes. Secondary recycling processes, including mechanical recycling, are significantly limited in their ability to handle contaminants such as toxic additives (phthalates and heavy metals), which persist in recycled products [37]. These additives can persist in recycled plastics and potentially migrate into packaged food or water, posing health risks [32], [37]. This limitation not only constrains recycling efficiency but also raises concerns regarding the safety of mechanically recycled plastic products. Mechanical recycling results in the production of goods with inferior performance characteristics compared to virgin plastics, with repeated processes leading to a decline in the mechanical and aesthetic properties of plastics owing to structural changes [2], [14], [32], [37]. In contrast, chemical recycling through pyrolysis effectively processes mixed, degraded, and contaminated plastic fractions that are unsuitable for mechanical recycling. Plastic materials, such as straws, disposable cutlery, and thin single-use carrier bags, are difficult to recycle mechanically because they cause blockages in sorting equipment and are rejected by recycling facilities, making them ideal candidates for pyrolysis [13]. By thermochemically converting these low-value fractions into fuels or chemical feedstocks, pyrolysis enables the recovery of value from materials that would otherwise be landfilled or openly burned [2], [32].

The global trend indicates that only approximately 9% of plastic waste is mechanically recycled, and the situation is even more challenging in sub-Saharan Africa, where only 4% of plastic waste is recycled owing to its highly heterogeneous nature and poor management resulting from limited source separation [2], [13]. Nigeria recycles less than 12% of its polymer waste annually, with only approximately 9% of plastic waste being recycled [10], [16]. In Ghana, despite active initiatives, less than 10% of plastic waste is collected or recycled, which is lower than the 6.7% of recycled waste in the Greater Accra Metropolitan Area (GAMA) [4], [31]. South Africa performs better, with reported rates between 16% and 46% [7], [14], [27]. In East Africa, waste is predominantly collected as unsorted mixed streams, as documented in Uganda, and mirrored by conditions prevailing in Tanzania’s municipal waste system, where informal recovery dominates, and multilayered, composite, and contaminated plastics have no viable end-of-life pathway. Under these operating conditions, mechanical recycling can only capture a small, high-quality fraction of the waste stream, leaving the majority of plastics unprocessed.

3.3.2. Scale-Up and Deployment of Plastic Pyrolysis in Sub-Saharan Africa

The reviewed evidence indicates that pyrolysis deployment in Sub-Saharan Africa has advanced from conceptual studies to laboratory-scale experiments, pilot-scale facilities, and large-scale simulated systems, reflecting the increasing technical maturity and scalability in the region. The pyrolysis development across Sub-Saharan Africa is specifically designed to transform heterogeneous plastic waste into energy and valuable products. At the experimental level, Nigeria has made significant strides with a portable semi-batch reactor weighing under 25 kg and consuming 2.5 kW of power, achieving a 64.58% liquid yield from the co-pyrolysis of polystyrene and cashew nut shells [19]. Another Nigerian setup processed 3.8 kg of waste LDPE sachet packaging, producing a high oil yield of 78.40% at 390°C, with catalytic upgrading yielding fuels comparable to lignite-grade energy values [12]. These results demonstrate the technical feasibility of achieving high fuel yields using relatively simple and low-energy reactor configurations in the future. Such low-power modular reactor configurations are particularly relevant in Tanzania, where informal plastic collection is prevalent. In Uganda, laboratory catalytic pyrolysis of mixed HDPE and LDPE waste collected from rubbish pits generated 105 mL of oil at 400°C, reducing the degradation onset to 170°C, significantly lower than the 205°C required for thermal-only processes [35]. This reduction underscores the role of catalysis in enhancing process efficiency and lowering operational energy requirements.

In the Ashanti Region of Ghana, a 400-kW hybrid waste-to-energy plant has been established that can process 50 tons of MSW daily. This facility includes a pyrolysis unit that converts 1 ton of mixed plastic waste per day into bio-oil for a 100-kW CHP engine and syngas for an additional 50-kW CHP system [4]. This pilot project exemplifies the operational integration of pyrolysis within multi-technology renewable energy systems, effectively bridging the gap between laboratory success and real-world applications. South Africa, a leading producer of plastic waste in Africa, has advanced beyond the initial phase of plastic waste management testing. Waste polypropylene is commercially converted into diesel-range fuels via pyrolysis [7], [41]. Despite weak regulatory frameworks and financial challenges, Tanzania is advancing from laboratory to pilot-scale pyrolysis research. Early stage innovation, particularly by Recyclable Energy Solutions, has led to the development of a working prototype that transforms waste plastic bottles into liquid fuel and incorporates informal waste collectors into the business.

Large-scale simulation studies have demonstrated the potential scalability and economic viability of pyrolysis processes. In Sudan, modelling an LDPE-based pyrolysis power plant with a capacity of 37.5 $\text{ton}\cdot\text{h}^{-1}$ revealed that operating at 700°C yields the highest returns, producing an NPV of 91.52 million and a payback period of just 4.7 years from a 25-million investment [31]. Similarly, techno-economic analyses across 12 Nigerian cities estimated a bio-oil production potential of 209 tons/year and an electricity generation capacity of 87.5 MW, confirming the feasibility of urban deployment of the technology [5]. Although a Johannesburg-based assessment ranked pyrolysis fourth among waste-to-energy technologies, it demonstrated strong financial performance, reporting the lowest plant establishment cost and a positive NPV of 247.49×10^6 USD for distributed generation scenarios, highlighting its potential to divert significant post-recycled waste from landfills [1]. These economic indicators suggest that pyrolysis can be financially competitive, even when it is not ranked as the top-performing technology. Overall, although Tanzania lags behind Ghana and South Africa in formal pilot-scale pyrolysis deployment, the presence of operational prototypes, abundant plastic waste, and strong informal collection networks create a favorable context for scaling up pyrolysis. The experiences of neighbouring and regional countries demonstrate that Tanzania is not constrained by technological feasibility but rather by institutional support, financing mechanisms, and regulatory alignment. Addressing these barriers would allow Tanzania to transition from experimental prototypes to pilot-scale projects.

4. KNOWLEDGE GAP AND AREAS FOR FURTHER RESEARCH

This review reveals several important knowledge gaps regarding the application of pyrolysis for plastic waste management in sub-Saharan Africa. Although existing studies demonstrate the environmental and energy recovery potential of pyrolysis, the available evidence remains fragmented and is largely based on laboratory experiments, pilot demonstrations, and simulation models rather than long-term operational systems. Most studies have focused on technical parameters, such as product yields, calorific values, and greenhouse gas mitigation potential, whereas limited research has evaluated the long-term operational performance, reliability, and stability of pyrolysis systems under continuous real-world conditions. Consequently, there is insufficient empirical evidence on how these systems perform when exposed to fluctuating waste compositions, operational interruptions, and infrastructure constraints that are common in urban waste management systems across the region. Furthermore, the literature provides limited comprehensive techno-economic assessments that consider the full lifecycle costs, market stability of pyrolysis products, and financial risks associated with scaling the technology. Although some studies report positive economic indicators, such as favorable net present values or payback periods, these assessments are uneven across countries and often rely on modelling assumptions rather than on operational data. Similarly, feedstock variability and waste segregation challenges, which strongly influence fuel yields and process efficiency, remain inadequately studied in the context of municipal waste systems characterized by heterogeneous and poorly sorted plastics.

In addition, the institutional, policy, and socio-technological dimensions remain underexplored. Existing research rarely evaluates regulatory readiness, governance frameworks, and public acceptance of pyrolysis-based waste management systems, despite the fact that these factors are critical for large-scale implementation in sub-Saharan Africa. Consequently, future studies should integrate technical, economic, environmental, and social analyses to provide a more holistic understanding of pyrolysis. Therefore, further research should prioritize long-term operational studies, standardized life-cycle assessments, and detailed techno-economic analyses, while also examining policy frameworks, financing mechanisms, and stakeholder participation to support the sustainable and scalable implementation of pyrolysis technologies for plastic waste management in sub-Saharan Africa.

5. CONCLUSION

This review evaluated the effectiveness of pyrolysis as a waste-to-energy solution for managing heterogeneous plastic waste in sub-Saharan Africa. The strongest evidence emerging from the reviewed studies is the ability of pyrolysis to achieve substantial greenhouse gas reductions, including net-negative emissions in some contexts, positioning pyrolysis as a viable contributor to the national climate commitments and low-carbon development pathways. Additionally, it highlights the technology's ability to recover high-value liquid fuels, syngas, and biochar with calorific values comparable to those of conventional fossil fuels, confirming its strong waste-to-wealth potential, thereby supporting circular economy objectives, urban resilience, and energy diversification. Moreover, the demonstrated technical flexibility of pyrolysis systems, including decentralized, pilot-scale, and hybrid configurations, suggests that this technology can be adapted to diverse urban contexts and resource constraints typical of sub-Saharan African cities. These attributes underscore pyrolysis as a complementary technology within integrated waste management frameworks rather than a replacement for waste prevention and recycling. Despite these strengths, there are significant knowledge gaps in the literature.

Limited evidence exists on long-term operational performance, system reliability under continuous operation, and real-world emission control effectiveness beyond experimental and simulation studies. Economic viability assessments are uneven across countries, with insufficient analyses of financing models, market stability of pyrolysis products, and sensitivity to feedstock variability. Furthermore, social and institutional dimensions, such as policy enforcement, public acceptance, informal sector integration, and regulatory readiness, remain underexplored, despite their importance for large-scale deployment. Thus, future research should prioritize longitudinal operational studies, standardized life-cycle and techno-economic assessments, and integrated socio-technical analyses to support evidence-based policy and investment decisions. Addressing these gaps is critical for translating the demonstrated technical and environmental potential of pyrolysis into scalable, sustainable, and socially acceptable solutions for plastic waste management in sub-Saharan Africa.

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