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Review Article

Plastic Waste Pyrolysis Research: A Comprehensive Bibliometric Analysis of Scientific Trends and Environmental Implications

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Abstract: Plastic waste pyrolysis is a promising method to manage plastic pollution by turning waste into useful fuels and chemicals. This study analyzes research on plastic waste pyrolysis from 2000 to 2025 using 2,019 articles from the Web of Science database. Using bibliometric tools, it examines trends in publications, key authors and institutions, popular journals, main research topics, and international cooperation. Findings show a rapid increase in research since 2017, driven by growing environmental awareness and new policies. The top contributing countries are China, India, the United States, and European countries such as Spain, Poland, and Italy. Leading institutions include Ghent University and Universiti Teknologi Malaysia. Main research areas cover catalytic and co-pyrolysis techniques, reactor design, product analysis, and environmental effects. New trends focus on microwave-assisted pyrolysis, hydrogen production, and circular economy approaches. Despite progress, challenges remain such as improving process efficiency, assessing environmental impacts, and addressing under-researched plastics. The study highlights the collaborative and interdisciplinary nature of the field, combining engineering and environmental science. This overview helps researchers and decision-makers understand key topics and gaps. Continued research and cooperation are needed to develop effective, large-scale pyrolysis technologies that can help solve the global plastic waste problem and support sustainable resource use.

Keywords: *Bibliometric Analysis, Bibliometrix, Plastic Waste, Pyrolysis.*

Plastik Atık Pirolizi Araştırmaları: Bilimsel Eğilimler ve Çevresel Etkiler Üzerine Kapsamlı Bir Bibliyometrik Analiz

Öz. Plastik atıkların pirolizi, atıkların yararlı yakıt ve kimyasallara dönüştürülmesi yoluyla plastik kirliliğini yönetmek için umut verici bir yöntemdir. Bu çalışma, 2000-2025 yılları arasında Web of Science veri tabanındaki 2.019 makale üzerinden plastik atık pirolizi üzerine yapılan araştırmaları analiz etmektedir. Bibliyometrik araçlar kullanılarak yayın eğilimleri, öne çıkan yazarlar ve kurumlar, popüler dergiler, ana araştırma konuları ve uluslararası iş birlikleri incelenmiştir. Bulgular, 2017 yılından itibaren çevresel farkındalığın artması ve yeni politikaların etkisiyle araştırmalarda hızlı bir artış olduğunu göstermektedir. En fazla katkı sağlayan ülkeler Çin, Hindistan, ABD ve İspanya, Polonya ve İtalya gibi Avrupa ülkeleridir. Öne çıkan kurumlar arasında Ghent Üniversitesi ve Malezya Teknoloji Üniversitesi yer almaktadır. Temel araştırma alanları arasında katalitik ve eş-piroliz teknikleri, reaktör tasarımı, ürün analizi ve çevresel etkiler bulunmaktadır. Yeni araştırma eğilimleri arasında mikrodalga destekli piroliz, hidrojen üretimi ve döngüsel ekonomi yaklaşımları öne çıkmaktadır. Tüm ilerlemelere rağmen, süreç verimliliğinin artırılması, çevresel etkilerin değerlendirilmesi ve yeterince araştırılmamış plastik türlerine odaklanılması gibi zorluklar sürmektedir. Bu çalışma, mühendislik ve çevre bilimlerini birleştiren iş birliğine dayalı ve disiplinler arası yapısıyla bu alandaki gelişmeleri özetlemekte; araştırmacılar ve karar vericiler için önemli konu başlıkları ve araştırma boşluklarını ortaya koymaktadır. Küresel plastik atık sorununa çözüm sağlamak ve sürdürülebilir

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kaynak kullanımı hedefini desteklemek için etkili ve büyük ölçekli piroliz teknolojilerinin geliştirilmesi adına sürekli araştırma ve iş birliği gerekmektedir.

Anahtar Kelimeler: *Bibliyometrik Analiz, Bibliometrix, Plastik Atık, Piroliz.*

1. Introduction

Plastic materials are extensively utilized in modern industry and daily life due to their advantageous properties such as light weight, durability, chemical resistance, and low cost. However, these very benefits also make plastics highly resistant to environmental degradation, positioning them as a major contributor to global environmental pollution. In particular, the uncontrolled consumption of single-use plastics and their low recycling rates pose severe threats to both terrestrial and marine ecosystems. Traditional mechanical recycling methods are only applicable to a limited range of plastic types and often prove inadequate in processing contaminated, multilayered, or mixed plastic waste [1]. This situation underscores the urgent need for more inclusive and efficient transformation technologies.

Pyrolysis, a thermochemical recycling method, involves the decomposition of plastic waste in an oxygen-free environment by heating it typically within the temperature range of 300-900 °C. This process relies on thermal cracking mechanisms to yield solid residues (char), liquid products (pyrolytic oil), and gaseous products (pyrolytic gas or syngas) [2,3]. Each of these products possesses distinct economic and environmental value. For instance, char can be utilized for activated carbon production or as a soil amendment (biochar); pyrolytic oil may serve as a feedstock in refinery operations or as an alternative fuel [4]. Pyrolytic gases such as H_2, CO, and CH_4 can be recirculated as an internal energy source within the system [5]. Moreover, syngas functions as a valuable intermediate in numerous industrial applications, including the production of Fischer-Tropsch (FT) liquids, methanol, and ammonia.

The efficiency and product quality of pyrolysis processes are directly influenced by parameters such as operating temperature, heating rate, type of catalyst used, and the nature of the plastic feedstock [6-8]. In this context, advanced techniques such as catalytic pyrolysis and microwave-assisted pyrolysis offer significant potential for enhanced product quality and improved energy efficiency. The type of plastic processed plays a crucial role in determining the composition of pyrolysis products [9,10]. For instance, polyolefins such as polyethylene (PE) and polypropylene (PP) predominantly yield liquid and gaseous products, whereas polystyrene (PS) primarily decomposes into aromatic hydrocarbons [11,12]. Plastics containing chlorine, such as polyvinyl chloride (PVC), generate harmful by-products like acidic hydrogen chloride (HCl) gas, necessitating appropriate gas treatment systems and pre-processing steps to ensure environmental and operational safety.

In recent years, the number of studies on pyrolysis has increased significantly in the literature [13,14]. For instance, Al-Salem et al. [15] reported that common plastics such as PE and PP yield high amounts of liquid products. Kalargaris et al. [16] showed that plastic pyrolysis oils produced at different temperatures can be successfully used in direct injection diesel engines, with properties similar to those of diesel fuel and performance dependent on pyrolysis conditions. Microwave-assisted pyrolysis has emerged as a promising method due to its improved thermal uniformity and environmentally friendly characteristics.

Catalyst utilization plays a critical role in optimizing process performance. Zeolite-based catalysts such as ZSM-5 enhance the production of aromatics, while metal oxides like Al_2O_3, CaO, and MgO not only improve the yield of liquid products but also help capture HCl released from chlorinated plastics, thus mitigating environmental impact [17-20]. Transition metal-supported catalysts, including Ni, Co, and Fe contribute to better hydrocarbon distribution and reduce the formation of undesirable by-products [21,22]. The selection of a suitable catalyst should consider the targeted product profile, environmental regulations, and economic constraints.

In conclusion, pyrolysis technology aligns closely with the United Nations Sustainable Development Goal (SDG) 12: Responsible Consumption and Production-particularly Target 12.5, which aims to “substantially reduce waste generation through prevention, reduction, recycling, and reuse by 2030.” Pyrolysis contributes to circular economy practices by transforming complex plastic waste into reusable resources. It offers alternative energy sources to fossil fuels, reduces the carbon footprint, decreases the need for landfilling, and enables the safe disposal of non-recyclable plastics. Thus, pyrolysis establishes a strong balance between environmental sustainability and economic benefit.

The production of scientific knowledge is progressing at an accelerating pace, making the systematic evaluation of this growing body of literature increasingly important. In this context, bibliometric analysis emerges as a powerful method for the quantitative assessment of scientific publications [23]. Bibliometric analysis enables the examination of literature related to a specific topic, field, author, or publication based on metrics such as the number of publications, citation counts, author collaborations, institutional affiliations, national contributions, keyword trends, and temporal patterns [24]. This method is widely used to track developmental trends within a research domain, identify the most productive authors, institutions, countries, and journals, uncover patterns of scientific collaboration and network structures, detect knowledge gaps, and shed light on potential future research directions. Furthermore, it facilitates the exploration of relationships between conceptual structures through clustering and co-occurrence analyses [25].

Among the most frequently used software tools in bibliometric studies are Gephi [26], VOSviewer [27], CiteSpace [28] , and Bibliometrix [29]. These tools support a range of analyses, including the visualization of scientific networks, keyword analysis, collaboration maps, and trend analyses. Commonly used data sources for bibliometric research include academic databases such as Web of Science (WoS), Scopus, Dimensions, PubMed, and, to a lesser extent, Google Scholar [30].

Web of Science, developed by Clarivate Analytics, is

recognized as the most extensively used platform for scientific citation indexing and analytical research worldwide. In contrast to other commonly used databases, WoS offers a broader and more structured coverage, providing access to over 21,000 peer-reviewed journals across more than 250 disciplines in the sciences, social sciences, and humanities [31]. For these reasons, WoS was selected as the data source in this study.

In conclusion, bibliometric analysis is an effective and objective tool for understanding the developmental dynamics of a specific scientific field, evaluating research trends, and identifying gaps in the literature [32]. Due to its capacity to support literature reviews with robust empirical data, bibliometric methods are widely applied in thesis studies, review articles, research projects, and science policy development. When supported by the appropriate choice of software and data sources, such analyses provide researchers with an opportunity to examine scientific production processes in a more comprehensive and systematic manner [33].

In this study, a comprehensive bibliometric analysis of the literature on plastic waste pyrolysis was performed using bibliographic data retrieved from the Web of Science database and analyzed with the R-based Bibliometrix/Biblioshiny tool. While several recent studies have carried out bibliometric assessments on specific facets of plastic waste pyrolysis such as polystyrene-focused analyses [34], the characterization of waxy products [35], or investigations of co-pyrolysis processes [36,37] these works typically focus on narrower research scopes, limited time frames, or specific materials and process categories. In contrast, the present study provides a comprehensive and up-to-date bibliometric overview of the entire field of plastic waste pyrolysis over a 25-year period (2000-2025), encompassing all plastic types, processes, and key thematic trends. Unlike previous analyses, which often center on a single polymer, process, or a limited set of keywords, this research utilizes a robust dataset of 2,019 SCIE-indexed research articles extracted from the Web of Science and employs a multi-dimensional analysis, including annual publication trends, author and institution networks, thematic mapping, and keyword evolution using Bibliometrix. As a result, this study offers a broader and more holistic perspective, identifies current research gaps, and provides strategic insights for future studies in the field [38].

Compared to earlier bibliometric studies, this research demonstrates several key differences and unique contributions. For example, Nabgan et al. [39] conducted a bibliometric and critical review focused specifically on catalytic pyrolysis of plastic waste using non-precious metal catalysts, combining bibliometric mapping with a detailed evaluation of catalyst types and reaction mechanisms. However, their analysis centers on a specific technical theme catalysis and, while offering valuable insights into catalyst development and performance, does not provide a comprehensive thematic or interdisciplinary overview of the entire plastic pyrolysis literature. Similarly, Wong et al. [40] performed a bibliometric analysis on the upcycling of plastic waste to carbon nanomaterials, focusing exclusively on the synthesis of advanced carbon products such as carbon nanotubes and graphene. Their work is limited in scope, covering just 120 articles published between 2000 and 2019 and restricting the analysis to a single application area within plastic waste valorization.

In summary, the present study adopts a much broader and more inclusive perspective, with a significantly larger dataset and a multi-dimensional analysis framework. This allows for a more holistic understanding of research development, knowledge gaps, and future directions in plastic waste pyrolysis, offering valuable guidance for both researchers and policymakers as the field continues to evolve rapidly.

2. Methodology

This study aims to examine the literature on pyrolysis of plastic waste from 2000 to 2025 through a bibliometric perspective. The analysis identifies research trends, prominent publications, existing research gaps, and the most influential scientific sources within the field. Data were obtained from the Web of Science Core Collection database using the keywords “plastic waste”, and “pyrolysis” in combination. The selected keywords were searched within the topic field, which includes the title, abstract, author keywords, and keyword plus. To ensure the relevance and scientific rigor of the dataset, only research articles indexed in the Science Citation Index Expanded (SCIE) were included in the analysis. As a result, a total of 2,019 documents were retrieved. Although the first publication related to the pyrolysis of plastic waste was indexed in Web of Science in 1980, no relevant documents were found between 1981 and 1990. Moreover, only 25 publications were identified between 1990 and 1999. Due to the limited number of studies conducted in these earlier years, the time frame of 2000 to 2025 was selected for this bibliometric analysis in order to ensure data density, analytical clarity, and statistical relevance. The data corresponding to these documents were downloaded in BibTeX format on May 22, 2025, and subsequently analyzed using the Bibliometrix 4.3.0 package within the R Studio (version 4.4.2).

3. Results and Discussion

The pyrolysis of plastic waste has become an increasingly significant research area in the context of sustainable waste management and alternative energy production. The bibliometric data presented in Table 1, covering the years 2000-2025, comprehensively illustrates the developmental trajectory and research trends in this field. A total of 2,019 academic documents were analyzed, published across 345 distinct sources. This high volume of publications and source diversity highlights the multidisciplinary nature of pyrolysis research and its widespread academic appeal.

Table 1 Overview of key bibliometric metrics in plastic waste pyrolysis research

Description	Indicators
Timespan	2000-2025
Documents (article, review article)	2,019
Sources (Journals, Books, etc.)	345
Annual Growth Rate %	19.64
Document Average Age	3.69
Average citations per doc	34.13

References	68,488
Author's Keywords	4,063
Authors	8,506
Authors of single-authored docs	45
Co-Authors per Doc	5.89
International co-authorships %	32.54

The field exhibits a remarkably high annual growth rate of 19.64%, indicating a rising level of interest among researchers and a growing relevance driven by global environmental concerns. These documents involved contributions from 8,506 different authors, with only 45 published as single-authored papers. This reflects the predominantly collaborative nature of research in this domain, characterized by multi-authored outputs. On average, each publication was co-authored by 5.89 researchers, suggesting that an interdisciplinary research culture prevails bringing together experts from engineering, environmental sciences, chemistry, and energy-related disciplines. The international co-authorships rate stands at a notable 32.54%, underscoring that pyrolysis of plastic waste is a globally relevant issue addressed through transnational academic partnerships. This level of cooperation signifies a broader scientific solidarity in pursuit of the goals of sustainable development and circular economy practices. The documents analyzed collectively cite 68,488 references, which indicates a literature-intensive, systematic, and theoretically grounded research base. Additionally, the use of 4,063 unique keywords reflects the conceptual diversity of pyrolysis technology. Key subtopics such as thermal and catalytic pyrolysis, the characteristics of solid, liquid, and gaseous products, reactor design, and environmental implications are extensively explored in the literature. The average age of the documents is 3.69 years, indicating that the majority of publications in this field are relatively recent. This points to a sharp increase in academic attention toward pyrolysis technologies in recent years. Furthermore, the documents have received an average of 34.13 citations each, signifying strong academic impact and influence in shaping the direction of future research.

In conclusion, the topic of plastic waste pyrolysis stands out as a dynamic research domain characterized by rapid growth, international and interdisciplinary collaboration, strong academic impact, and conceptual richness. The bibliometric indicators obtained reveal that scientific output in this field is advancing not only quantitatively but also qualitatively, making a significant contribution to the vision of a sustainable future.

3.1. Productivity Analysis

3.1.1. Annual Scientific Productivity

Figure 1 illustrates the annual scientific output in the field of plastic waste pyrolysis between 2000 and 2025, as measured by the number of published articles. During the period from 2000 to 2016, the annual number of publications remained relatively low and stable, typically ranging between 0 and 20 articles. This trend may indicate that the topic had not yet gained significant traction within the research community or that technological limitations constrained its exploration.

Starting in 2017, a gradual increase in publication numbers becomes evident. This upward trend reflects a growing academic interest driven by the emerging discourse on sustainability, circular economy principles, and the global plastic waste crisis. Between 2020 and 2023, a noticeable surge in scientific output occurred, marking a period of accelerated growth. The post-2020 phase is characterized by an exponential rise in annual publications, peaking in 2023 with over 450 articles published. This sharp increase can be attributed not only to heightened research interest but also to broader policy and financial drivers such as the European Green Deal, stricter plastic regulations, and global energy transition initiatives highlighting the strategic importance and urgency of advancing pyrolysis technologies for sustainable development.

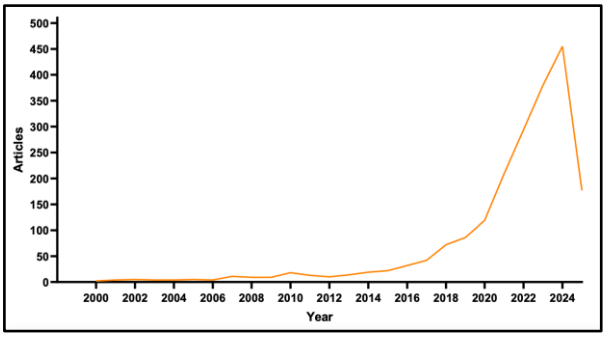

Figure 1. *Trend of annual publications in the field of plastic waste pyrolysis*

The decline observed after 2024 is attributed to the fact that the data for the year 2025 are not yet complete. As of May 2025, the number of publications has already reached 177, suggesting that the total output is likely to increase significantly by the end of the year, in line with the recent growth trend. In summary, the field of plastic waste pyrolysis has experienced a remarkable surge in scientific publications, particularly over the past five years, indicating a substantial rise in awareness and interest in this research area.

3.1.2. Average Annual Citations

The analysis of annual average citation counts serves as a valuable indicator for identifying the period during which the field gained visibility and determining which years had the greatest impact. Figure 2 presents the annual average number of citations. Citation trends are generally associated with the quality of the publications and the level of interest the research area attracts.

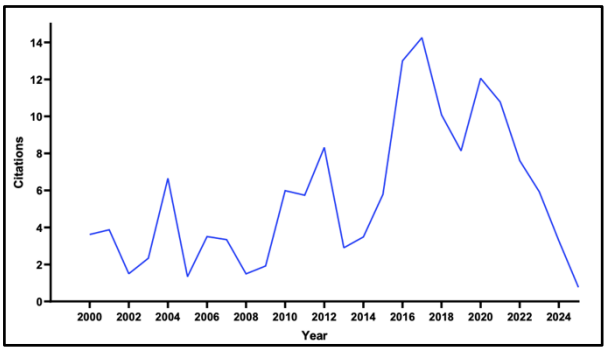

Figure 2. *Average citations per year in plastic waste pyrolysis research*

According to Figure 2, the period between 2000 and 2010 was characterized by fluctuating yet generally low average citation counts, typically ranging between 2 and 6 citations per year. This trend can be attributed to the limited volume of publications and the low scientific visibility of the field during those years. Particularly between 2006 and 2009, citation performance remained weak, suggesting that the studies published in this period may not have yet reached a broader academic audience. A significant upward trend began around 2014, with average citation counts peaking in 2017 and 2018, surpassing 15 citations per year. This increase is likely associated with growing academic recognition of earlier works and the rising visibility of the field as a whole. Studies published after 2015 appear to have garnered more attention, both in terms of quantity and scholarly impact. From 2019 onward, a noticeable downward trend in average citations is observed. Possible explanations for this decline include the limited time newer publications have had to accumulate citations or the shorter citation window for articles published in 2023 and 2024, which naturally leads to lower citation counts in those recent years.

3.1.3. Most Relevant Authors

Table 2 presents the top authors in plastic waste pyrolysis research, highlighting their productivity and scientific impact through key metrics such as article count, Average Publication Year (APY), Average Citations (AC), and Total Link Strength (TLS). Van Geem, K. M. from Ghent University stands out as the most prolific author with 32 publications, an APY of 2,019.7, and a strong citation impact (AC: 37.1). Kwon, E. E. and Lee, J. both from South Korea follow closely with 25 and 24 articles respectively, maintaining high average citations and recent APYs, indicating their continued activity and influence in the field. Authors such as Jung, S., Park, YK., and Kusenberg, M. further underscore the strong presence of South Korean and Belgian researchers. Notably, Bilbao, J. and Olazar, M. from the University of the Basque Country are distinguished by particularly high average citation rates (45.3 and 40.9, respectively), reflecting the significant impact of their work even if their total publication counts are somewhat lower. Calero, M. (University of Granada, Spain) and Sajdak, M. (Silesian University of Technology, Poland) also contribute meaningfully to the field, each with 14-16 articles and solid citation metrics. The presence of high TLS values across most authors signals their active engagement in research collaboration and co-authorship networks.

The assessment of APY provides valuable insight into an author's productivity and scientific impact. A more recent APY indicates that the author is actively contributing to the field, reflecting current relevance and sustained scholarly output. Additionally, APY contextualizes citation metrics by accounting for the time available for citations to accumulate, thus offering a fairer evaluation of newer contributions. It also helps distinguish between early pioneers and emerging researchers, revealing career trajectories and topical engagement. Overall, APY enhances the interpretation of bibliometric data by incorporating the temporal dimension of scholarly activity.

In summary, the table illustrates that plastic waste pyrolysis research is shaped by a relatively concentrated group of highly productive and influential scholars, predominantly based in Europe and East Asia, whose work continues to drive innovation and advance scientific knowledge in this domain.

Table 2 Top Authors in Plastic Waste Pyrolysis Research

Rank	Author	Country	Institution	Article	APY	AC	TLS
1	Van Geem, K. M.	Belgium	Ghent University	32	2,019.7	37.1	12
2	Kwon, E. E.	South Korea	Hanyang University	25	2,019.9	34.3	11
3	Lee, J.	South Korea	Sungkyunkwan University	24	2,020.1	31.8	11
4	Jung, S.	South Korea	Kyungpook National University	22	2,020.2	26.5	9
5	Bilbao, J.	Spain	University of the Basque Country	17	2,014.6	45.3	18
6	Calero, M.	Spain	University of Granada	16	2,015.8	27.2	7
7	Olazar, M.	Spain	University of the Basque Country	15	2,015.0	40.9	16
8	Park, YK.	South Korea	University of Seoul	15	2,018.3	33.7	10
9	Kusenberg, M.	Belgium	Ghent University	14	2,021.4	22.6	6
10	Sajdak, M.	Poland	Silesian University of Technology	14	2,016,8	28.1	8

3.1.4. Most Relevant Institutions

As shown in Table 3, Ghent University (Belgium) ranks first with a total of 112 publications, making it the most productive institution in the field of plastic waste pyrolysis. It is followed by Universiti Teknologi Malaysia with 77 articles, reflecting

Southeast Asia's increasing focus on sustainable waste and energy research. King Fahd University of Petroleum and Minerals (Saudi Arabia) and Nanyang Technological University (Singapore) share third place with 73 publications each, highlighting their strong regional leadership in applied sciences. Sungkyunkwan University from South Korea ranks fifth with 67 publications, while the University of Granada (Spain), University of Pannonia (Hungary), and three additional South Korean institutions; Ajou University, University of Seoul, and Hanyang University round out the top ten with article counts ranging from 49 to 56. Table 3 clearly demonstrates the geographic diversity of research productivity, with leading contributions emerging from Europe, Asia, and the Middle East.

Table 3. Top Institutions in Plastic Waste Pyrolysis Research

Rank	Institution	Country	Article
1	Ghent University	Belgium	112
2	Universiti Teknologi Malaysia	Malaysia	77
3	King Fahd University of Petroleum and Minerals	Saudi Arabia	73
4	Nanyang Technological University	Singapore	73
5	Sungkyunkwan University	South Korea	67
6	University of Granada	Spain	56
7	University of Pannonia	Hungary	54
8	Ajou University	South Korea	53
9	University of Seoul	South Korea	51
10	Hanyang University	South Korea	49

3.1.5. Most Relevant Journals

Table 4 lists the top scientific journals publishing research on plastic waste pyrolysis, along with the number of articles each has contributed to the field. The Journal of Analytical and Applied Pyrolysis leads by a significant margin with 108 articles, followed by Fuel with 87 articles, and Waste Management with 79 articles.

The distribution highlights the interdisciplinary nature of the field and the primary publication platforms preferred by researchers. The prominence of journals focused on chemical processes, energy, environmental management, and waste treatment such as Chemical Engineering Journal and Journal of Cleaner Production reflects the dual emphasis on energy conversion and sustainable waste management in pyrolysis research. These journals serve a broad academic audience, encompassing engineering, sustainability, and environmental science perspectives.

In summary, the table demonstrates the key journals that shape the scholarly landscape of plastic pyrolysis research and provides useful guidance for researchers regarding journal selection and literature review strategies.

Table 4 Top Journals in Plastic Waste Pyrolysis Research and Key Metrics

Rank	Journal	Article	h index	AC	IF (2024)	Quartile
1	Journal of Analytical and Applied Pyrolysis	108	30	37.1	5.8	Q1
2	Fuel	87	28	18.5	6.7	Q1
3	Waste Management	79	38	23.1	7.1	Q1
4	Chemical Engineering Journal	78	23	39.2	13.3	Q1
5	Journal of Cleaner Production	68	30	21.1	9.7	Q1
6	Process Safety and Environmental Protection	55	21	23.1	6.9	Q1
7	Energy Conversion and Management	52	32	26.2	9.9	Q1
8	Energies	51	12	15.7	3.0	Q3
9	Energy	51	22	31.7	9.0	Q1
10	Journal of Environmental Chemical Engineering	41	14	20.5	6.3	Q1

3.1.6. Most Relevant Countries

Figure 3 presents a world map illustrating the country-wise distribution of scientific publications on plastic waste pyrolysis. The color intensity on the map reflects the volume of research output from each country in this field. Darker blue shades indicate a higher number of publications, lighter blue shades represent lower publication counts, while grey areas denote countries with no recorded publications.

This map reveals that while the topic of plastic waste pyrolysis has garnered broad global interest, the geographic distribution of this interest is notably uneven. China, represented in the darkest blue, is the leading country in terms of publication output in this field. This dominance likely reflects China's substantial scientific investment in addressing its plastic waste challenges and its strategic prioritization of pyrolysis technologies. India and the United States also demonstrate significant scientific contributions, ranking just behind China. In particular, India appears to have positioned plastic pyrolysis as a priority research area, likely due to its large population and corresponding high levels of waste generation. Several European countries such as Spain, Poland, Italy, Germany, and

France play an active role in the research landscape, aligning with the European Union's circular economy and sustainability policies. Countries like Brazil, Turkey, Indonesia, Mexico, and South Africa while shown in lighter blue tones, exhibit emerging research activity in this domain. In these regions, the growing severity of environmental issues and the pressing need for technological innovation have made pyrolysis a relevant research focus.

In contrast, parts of Central Africa, certain Middle Eastern countries, Central Asia, and small island states are either not represented or show minimal research output. This disparity may be attributed to limited access to scientific data, insufficient research infrastructure, or a lack of funding and institutional support in these areas.

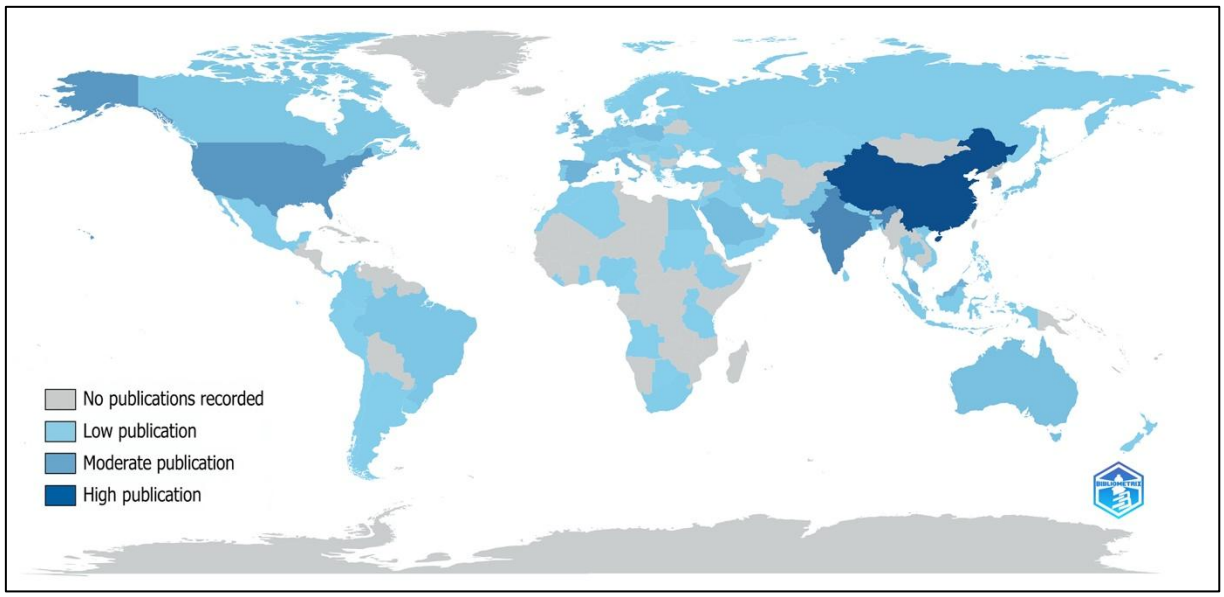

Figure 3. *Global Distribution of Scientific Publications on Plastic Waste Pyrolysis*

Figure 4 presents the annual distribution of scientific publications on plastic waste pyrolysis between 2000 and 2025, comparing the research output trends of five leading countries: China, India, the United States, South Korea and Spain. China has shown a remarkable surge since 2017, emerging as the top contributor with over 1,700 publications by 2025. This sharp rise reflects China's academic response to both the plastic waste crisis and its pursuit of renewable energy solutions.

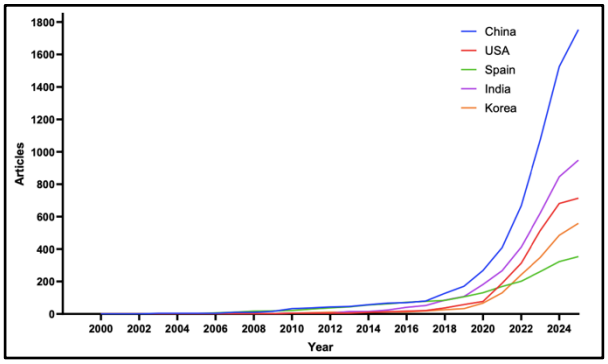

Figure 4. *Cumulative Research Output on Plastic Waste Pyrolysis by Country*

Following China, India demonstrates a notable upward trend, particularly after 2020, reaching approximately 1,000 publications by 2025. The United States, which had a relatively modest output between 2000 and 2015, significantly increased its contributions after 2018, reaching 714 publications by 2025, although still trailing behind China and India.

South Korea's contribution accelerated after 2019, with a sharp increase observed especially after 2022, bringing the total to 559 publications by 2025. Spain, despite being a leading contributor until 2015, has fallen behind in recent years, with its total publication count reaching 354 by 2025. This comparative analysis highlights both the global expansion of research interest in pyrolysis and the varying national dynamics influencing scholarly productivity in this field.

3.1.7. Most Cited Documents

The most globally cited publications are summarized in Table 5. These highly cited documents represent the foundational works and major review articles that have significantly shaped the development of plastic waste pyrolysis research over the past two decades. Among them, Ragaert et al. [41] on mechanical and chemical recycling, Sharuddin et al. [42] on pyrolysis reviews, and Li et al. [43] on microplastics have received the highest number of citations, reflecting their broad influence in the field.

Upon examination of Table 5, it is evident that the article "Mechanical and chemical recycling of solid plastic waste" by Ragaert et al. [41], published in Waste Management, stands out as the most highly cited publication with 1,835 citations.

This highlights the central role of mechanical and chemical recycling topics in the literature and underscores the significant impact of this work on the field. The study by Sharuddin et al. [42], published in Energy Conversion and Management, ranks second with 1,385 citations. This review has made a substantial contribution to both the theoretical and practical development of the field by providing a comprehensive overview of the pyrolysis process.

Table 5 Top Cited Documents in Plastic Waste Pyrolysis Research and Key Metrics

Rank	Author	Title	Citations	AC	Source Title
1	Ragaert et al, 2017 [41]	Mechanical and chemical recycling of solid plastic waste	1,835	203.89	Waste Management
2	Sharuddin et al. 2016 [42]	A review on pyrolysis of plastic wastes	1,385	138.5	Energy Conversion and Management
3	Li et al, 2018 [43]	Microplastics in freshwater systems: A review on occurrence, environmental effects, and methods for microplastics detection	1,369	171.13	Water Research
4	Vollmer et al, 2020 [44]	Beyond Mechanical Recycling: Giving New Life to Plastic Waste	1,050	175	Angewandte Chemie-International Edition
5	Al-Salem et al, 2017 [45]	A review on thermal and catalytic pyrolysis of plastic solid waste (PSW)	807	89.67	Journal Of Environmental Management
6	Ellis et al, 2021 [46]	Chemical and biological catalysis for plastics recycling and upcycling	654	130.8	Nature Catalysis
7	Panda et al, 2010 [47]	Thermolysis of waste plastics to liquid fuel A suitable method for plastic waste management and manufacture of value added products-A world prospective	647	40.44	Renewable & Sustainable Energy Reviews
8	Miandad et al, 2016 [48]	Catalytic pyrolysis of plastic waste: A review	643	64.3	Process Safety and Environmental Protection
9	Thiounn and Smith, 2020 [49]	Advances and approaches for chemical recycling of plastic waste	495	82.5	Journal Of Polymer Science
10	Wong et al, 2015 [50]	Current state and future prospects of plastic waste as source of fuel: A review	493	44.82	Renewable & Sustainable Energy Reviews

The article by Li et al. [43], published in *Water Research*, is third with 1,369 citations. This work focuses on the detection and environmental effects of microplastics, directly linking environmental science to the issue of plastic waste. The fourth and fifth most cited articles, by Vollmer et al. [44] and Al-Salem et al. [45], have contributed notably to the literature on chemical recycling and environmental management, respectively. All other studies listed in the table have received more than 200 citations each, indicating their status as influential works in the field.

Overall, this table demonstrates that both fundamental review articles and innovative research approaches in plastic waste pyrolysis and recycling receive significant attention in the literature. The most cited publications emphasize themes such as recycling technologies, pyrolysis mechanisms, environmental impacts of microplastics, and the circular economy. This trend reflects the prominence of interdisciplinary studies and practical solutions, which are driving forces in the development of the field. Citation counts, in particular, illustrate the critical role of both theoretical contributions and practice-oriented innovative approaches in advancing research. Consequently, the table highlights the foundational and seminal publications that shape the research landscape and guide future studies on plastic waste pyrolysis.

3.2. Keyword Analysis

Keyword analysis plays a crucial role in verifying the positioning of a research topic within the existing literature and in clarifying the scope of the study. Therefore, to validate the relevance and accuracy of the selected research domain, an Author Keyword analysis was first conducted. This analysis focused on the keywords provided directly by the authors, reflecting the core focus and conceptual framing of their work.

Subsequently, Keyword Plus analysis was performed to assess broader trends in keyword usage across the literature. This analysis aims to evaluate the thematic evolution of the field over time and to identify potential future directions for

research. Together, these analyses provide a comprehensive understanding of the intellectual structure and emerging themes within the domain of plastic waste pyrolysis.

3.2.1. *Author Keyword Analysis*

The frequency of keywords provided by authors is visualized in Figure 5 as a TreeMap analysis. This figure presents a graphical representation of the most frequently used author keywords in the bibliometric analysis of the plastic waste pyrolysis field. Each box in the TreeMap corresponds to a specific keyword, with the size of the box indicating the frequency of its occurrence across the analyzed documents. The percentage values represent the relative weight of each keyword within the total keyword set, providing insights into their prominence and centrality in the research domain.

In the TreeMap presented in Figure 5, pyrolysis (555 articles, 20%) and plastic waste (472 articles, 17%) appear as the two largest segments, underscoring their centrality to the core focus of this research domain. These keywords reflect the foundational themes of the analyzed literature.

Terms such as recycling (107, 4%), chemical recycling (102, 4%), circular economy (103, 4%), and upcycling (40, 1%) indicate that research in this area extends beyond physical processes, encompassing broader systemic and sustainability-oriented approaches. Catalytic pyrolysis (94, 3%) and co-pyrolysis (105, 4%) emerge as significant subcategories of pyrolysis, highlighting the growing academic interest in catalytic mechanisms and co-processing of multiple feedstocks. Additionally, keywords such as gasification (60, 2%) and combustion (36, 1%) point to the exploration of alternative thermochemical methods within the same research ecosystem. the prominence of polymer specific terms like PE (73, 3%), PP (70, 2%), and PS (47, 2%) reveals the most commonly studied plastic types. Among these, PE and PP are particularly notable as primary feedstocks in pyrolysis-related investigations.

In summary, this TreeMap reveals that research on plastic waste pyrolysis integrates both technical dimensions and sustainability considerations. The presence of diverse materials and process parameters such as catalysts, kinetics, and temperature demonstrate increasing depth and breadth in the field. As such, this keyword analysis serves as a strategic roadmap for identifying existing knowledge clusters and highlighting areas that merit further research attention.

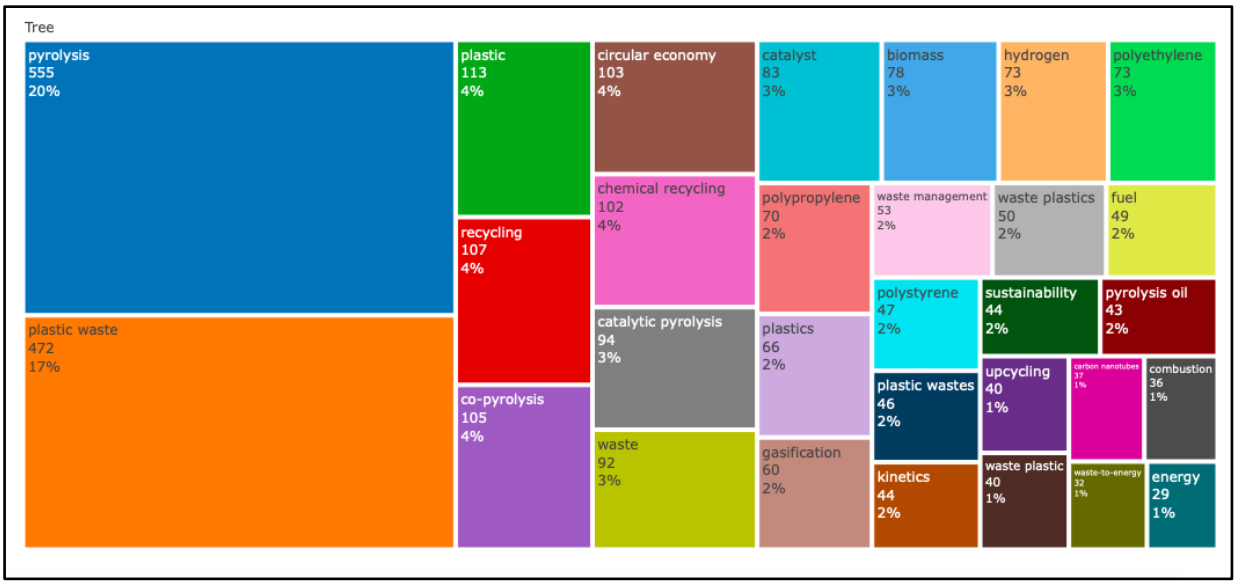

Figure 5. *TreeMap Analysis of Author Keywords in Plastic Waste Pyrolysis Research*

3.2.2. *Keyword Plus Analysis*

The visualization of all keyword occurrences in the literature is presented in Figure 6. This image, known as a word cloud, highlights the central themes and frequently studied topics within the research area. In the WordCloud, font size corresponds to the frequency of each term in the analyzed documents; thus, larger and capitalized words represent the most commonly encountered concepts in the literature.

Beyond simply illustrating prominent concepts, the word cloud provides valuable insights into the overall orientation of the field and the areas of focus among researchers. It serves as a useful tool for understanding prevailing trends and thematic concentrations. Moreover, the distribution and prominence of keywords not only reflect current research directions but also play a crucial role in identifying emerging topics and forecasting potential opportunities for academic collaboration and interdisciplinary exploration.

Upon examining Figure 6, it is evident that pyrolysis stands out as the most dominant keyword, underscoring its central role in the literature and affirming it as the core concept of the field. Other frequently occurring terms such as plastic waste, catalytic pyrolysis, thermal degradation, biomass, and degradation shed light on the materials subjected to pyrolysis and the specific pyrolytic methods explored.

Catalytic pyrolysis and thermal degradation represent the main types of processes applied, while the appearance of biomass indicates that pyrolysis is not limited to plastics but is also used with or in combination with biomass as an

alternative feedstock. The keyword co-pyrolysis highlights hybrid approaches where plastic waste is pyrolyzed alongside other materials, demonstrating the field's growing interest in integrated conversion strategies

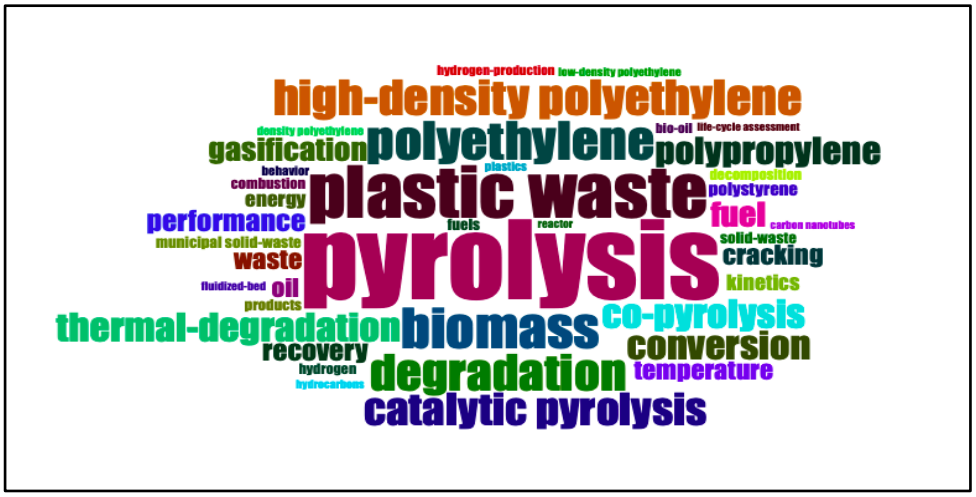

Figure 6. *Word Cloud of Major Themes in Plastic Waste Pyrolysis Research*

Material specific keywords such as PE, high density polyethylene (HDPE), low density polyethylene (LDPE), PP, and PS point to the most commonly studied polymers in pyrolysis research. These popular thermoplastics are frequently investigated under varying pyrolysis conditions, contributing to comparative insights across the literature. Keywords including gasification, cracking, conversion, fuel, energy, and performance underscore the research emphasis on technical results and process parameters in pyrolysis studies. Cracking refers to the underlying chemical transformation mechanisms, while temperature represents a critical process variable. Engineering and experimental design aspects are captured by keywords such as kinetics, reactor, fluidized-bed, and combustion, which emphasize the importance of process modeling and reactor configuration in this field. Lastly, terms such as municipal solid waste, life-cycle assessment, bio-oil, hydrogen production, and carbon nanotubes reveal the broader environmental and technological implications of pyrolysis. These keywords demonstrate how the field extends into sustainability assessments, advanced product recovery, and environmental impact evaluation, confirming that plastic pyrolysis is not only a waste treatment method but also a pathway toward high-value material and energy recovery.

3.3. Three-Field Plot Analysis

The three-field plot analysis is a type of diagram that simultaneously visualizes the relationships among three different bibliometric dimensions in scientific publications. By mapping the flow of information and connections, this method links entities such as authors, keywords, and publication sources. Additional dimensions such as countries, institutions, or years can also be incorporated into the analysis. This approach can answer questions such as which keywords authors are focusing on, in which journals these studies are published, and which countries contribute most to specific themes. It enables the identification of clusters of authors and publications around particular keywords, as well as the types of studies most frequently featured in specific journals. By clarifying which topics are most visible in which journals, the three-field plot provides valuable guidance for publication strategy. This analysis is particularly useful for researchers seeking to develop strategic publication plans or to explore patterns of scientific collaboration.

In this study, two separate three-field plot analyses were conducted for plastic waste pyrolysis research. In the first analysis, the fields considered were author keywords (DE), the most highly cited sources (SO), and the authors who conducted the studies (AU). Figure 7 presents the analysis based on author keywords, visualizing the relationships among key authors, their preferred keywords, and the leading publication sources in the field.

Pyrolysis and plastic waste stand out as the two most dominant keywords, clearly indicating that the central focus of the research is on these topics. Other prominent keywords such as recycling, catalyst, co-pyrolysis, chemical recycling, circular economy, and catalytic pyrolysis demonstrate that the literature covers both the technical aspects of pyrolysis and its sustainability dimensions. The Journal of Analytical and Applied Pyrolysis is identified as the leading, topic-focused journal in this area. Journals such as Waste Management, Fuel, Chemical Engineering Journal, and Journal of Cleaner Production are highlighted for their contributions in engineering, environmental, and sustainability contexts, while journals like Energy contribute to discussions on energy conversion and process safety.

The most productive and active researchers are prominent in areas including pyrolysis, energy production, environmental impacts, and chemical recycling. Some authors are connected to multiple journals and keywords, which indicates that their work spans both technical and applied dimensions of the field.

In conclusion, themes such as catalyst, chemical recycling, and circular economy are rapidly emerging, the literature is predominantly concentrated in journals rooted in energy, environmental engineering, and chemical engineering, and

certain authors act as central figures by contributing to a wide range of topics and journals within plastic waste pyrolysis research.

In the second analysis presented in Figure 8, the keywords used in the literature (ID) have been examined. By conducting a broader literature review, this approach provides deeper insights into the general trends and directions of the research field. Such analysis is useful for understanding the scope and disciplinary reach of the study. This type of analysis incorporates a comprehensive set of keywords derived from the bibliographic data of the articles, allowing for a more extensive mapping of thematic patterns and research connections within the field.

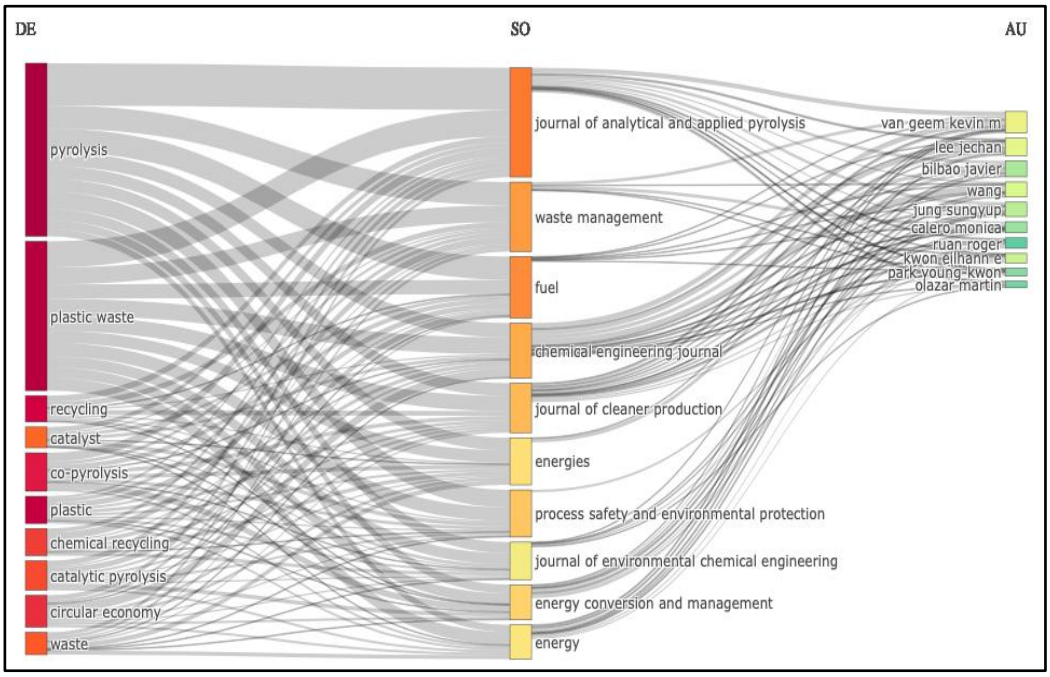

Figure 7. *Three-Field Plot of Keywords, Journals, and Authors in Plastic Waste Pyrolysis*

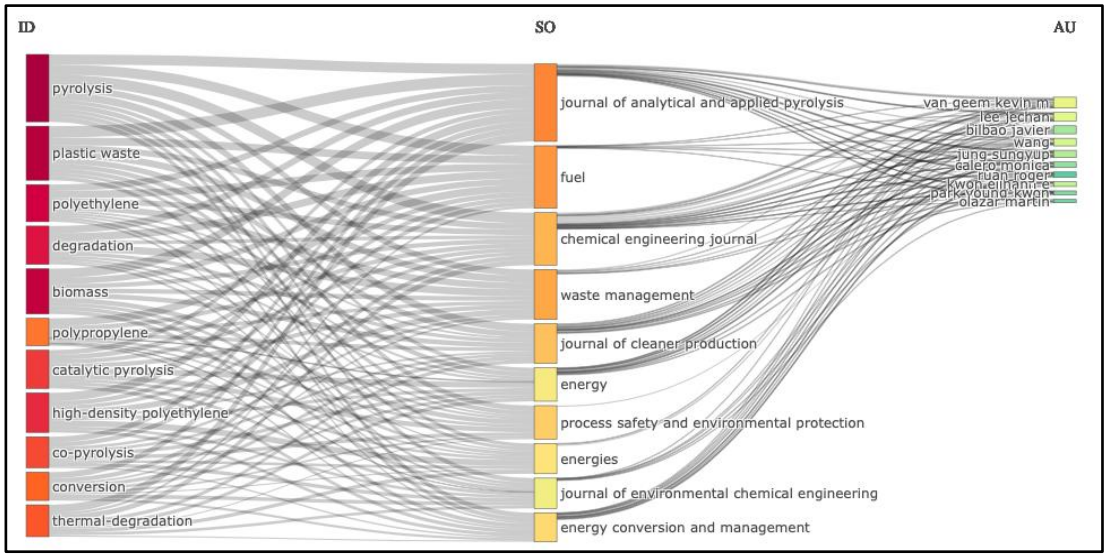

Figure 8. *Three-Field Plot of Keywords, Sources, and Authors in Plastic Waste Pyrolysis*

This plot, a wider range of keywords is included, such as PE, biomass, HDPE, co-pyrolysis, conversion, and thermal degradation. This broader approach provides a more comprehensive view of the thematic landscape and highlights additional research directions, such as the importance of specific plastic types, material-focused studies, and process-oriented keywords. The journal and author networks remain largely consistent, with leading journals and prolific researchers still forming the backbone of scholarly output.

3.4. Trend Topic Analysis

Figure 9 presents a visualization that analyzes the popularity and trends of prominent keywords in the literature over the years. This type of analysis serves as an important tool for understanding conceptual shifts within the research field and identifying which topics have gained prominence during specific time periods.

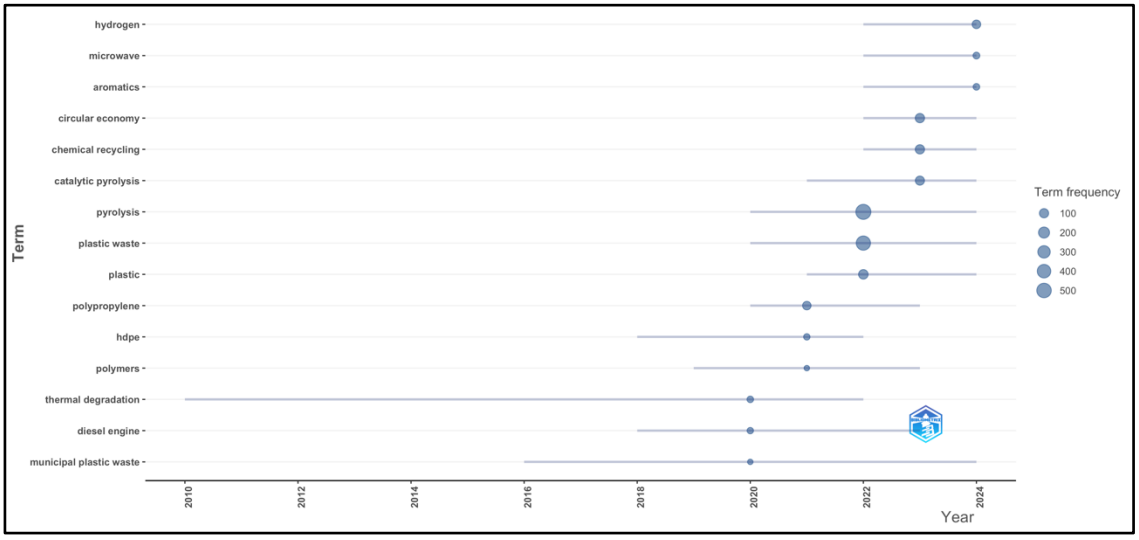

Figure 9. *Trend Topic Analysis of Major Keywords in Plastic Waste Pyrolysis Research*

This chart illustrates when and how frequently the most commonly used keywords in the field of plastic waste pyrolysis have emerged over time. The size of each bubble represents the frequency of the corresponding term. Core keywords such as pyrolysis, plastic waste, and plastic have remained consistently prominent since 2010, reaching their peak around 2022. Notably, pyrolysis stands out as the most dominant term both historically and in frequency, while plastic waste directly reflects the application area and is closely related to sustainability policies.

During 2021-2023, keywords such as hydrogen, microwave, and aromatics have gained prominence, signaling a shift towards new-generation products and innovative process technologies. These terms indicate a growing focus on hydrogen as an energy carrier produced via pyrolysis, the examination of microwave-assisted pyrolysis systems for improved energy efficiency, and the recovery of valuable aromatic compounds such as benzene and toluene. The emergence of circular economy and chemical recycling after 2022 highlights the integration of policy and systems-based approaches, signifying a conceptual shift from technical discussions towards circular resource management. This trend points to a growing recognition of pyrolysis as not only a recycling method but also a key component of circular economy strategies.

Material-specific keywords like polypropylene and HDPE have become more prominent since 2020, indicating an increased research focus on specific types of plastics and the comparative analysis of their conversion efficiencies. In contrast, terms such as thermal degradation, diesel engine, and municipal plastic waste were more visible between 2010 and 2018 but have declined in usage after 2020. The initial interest in using pyrolysis products as fuel for engines has waned as sustainability-oriented research has become more prevalent, and thermal degradation is now being replaced by more specialized processes like catalytic or microwave pyrolysis.

In summary, the period between 2010 and 2018 was characterized by fundamental processes and application studies, while 2018-2021 saw a diversification of materials and processes. In recent years, the focus has shifted to sustainability, circular economy, novel product recovery, and innovative process technologies. This analysis clearly demonstrates the temporal technical, environmental, and systemic transformation of the field of plastic waste pyrolysis, offering critical insights for understanding future directions and identifying emerging research gaps.

3.5. Thematic Map Analysis

Thematic maps provide a two-dimensional visualization of the key themes within a research field by illustrating both their relevance and level of development. The map is structured into four distinct quadrants: Motor Themes, Niche Themes, Emerging or Declining Themes, and Basic Themes. Each quadrant reflects the importance and maturity of the themes in the literature, offering valuable insights into areas that researchers may prioritize or explore further. Concepts are grouped into color-coded clusters, with each cluster representing a specific thematic area within the field.

Motor Themes are core topics that drive the research field and typically encompass both theoretical and applied studies. Niche Themes represent specialized areas that require a higher level of expertise and tend to focus on narrowly defined research interests. Basic Themes are widely represented in the literature but often require deeper investigation; topics such as usability and design, for instance, offer significant opportunities within this quadrant. Emerging or Declining Themes are generally underdeveloped but may hold high

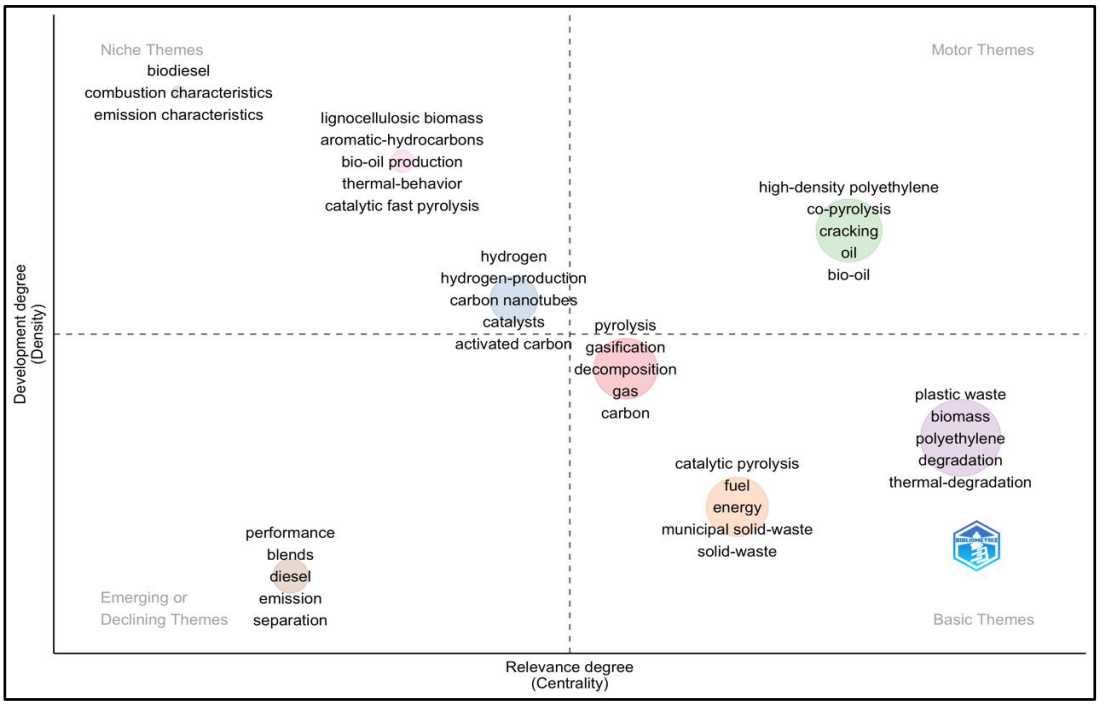

Figure 10. *Thematic map of plastic waste pyrolysis research*

potential for future growth, offering opportunities to open new avenues of inquiry.

As shown in Figure 10, the thematic map of plastic waste pyrolysis research classifies themes based on their centrality and density. In the upper-right quadrant, Motor Themes such as HDPE, co-pyrolysis, cracking, and bio-oil indicate well-developed and influential topics that are shaping the research agenda. In the upper-left quadrant, Niche Themes such as biodiesel, combustion characteristics, and aromatic hydrocarbons reflect highly specialized and deeply studied topics with limited connectivity to broader themes. Located in the lower-left quadrant, Emerging or Declining Themes such as performance, diesel, and separation represent either nascent or less explored areas that may present new research opportunities. Finally, the lower-right quadrant includes Basic Themes such as plastic waste, biomass, PE, and thermal degradation, which are central to the field yet in need of further theoretical and methodological development. Overall, Figure 7 highlights both mature and emerging research areas, offering a strategic perspective on current focal points and future directions in plastic pyrolysis studies.

4. Conclusions

This comprehensive bibliometric analysis of plastic waste pyrolysis research reveals significant growth and diversification in this critical field over the past 25 years. The study underscores pyrolysis as a pivotal technology contributing to sustainable waste management and circular economy initiatives, offering promising routes for converting plastic waste into valuable fuels and chemicals.

Key findings highlight an accelerating global research interest since 2017, driven by environmental imperatives and evolving energy policies. The increasing publication rates and citation impact reflect the growing academic and industrial attention to pyrolysis as a versatile solution addressing both plastic pollution and energy recovery. International collaborations are robust, with leading contributions from China, India, the United States and European Countries, signaling a widespread commitment to advancing pyrolysis technologies.

The analysis identifies several dominant research themes, including catalytic and co-pyrolysis methods, product characterization, reactor design, and environmental implications. Emerging trends focus on innovative techniques such as microwave-assisted pyrolysis and hydrogen production, alongside integrated circular economy frameworks emphasizing chemical recycling and upcycling. These thematic shifts illustrate the field's progression from fundamental process studies toward applied sustainability challenges and novel product development.

Despite this progress, the study also reveals knowledge gaps and underexplored areas, notably in performance optimization, life-cycle assessments, and comprehensive environmental impact analyses. The relative scarcity of research on certain plastic types and geographical disparities in scientific output suggest opportunities for broader inclusivity and targeted investigations.

In summary, plastic waste pyrolysis research has matured into a vibrant interdisciplinary domain that bridges engineering, environmental science, and sustainable development. Future

research should prioritize addressing the identified gaps, fostering cross-sectoral collaboration, and advancing scalable, economically viable pyrolysis technologies. Such efforts will be crucial in transforming plastic waste challenges into opportunities for sustainable resource management and clean energy production worldwide.

Future research in plastic waste pyrolysis should focus on process optimization and scale-up, development of novel and environmentally friendly catalysts, and comprehensive life cycle and environmental impact assessments. Additionally, studies should explore the integration of pyrolysis within circular economy frameworks, address emerging waste streams and contaminants, and investigate recovery of high-value products. These approaches will enhance the sustainability of the technology and support its industrial implementation.

Authors Contributions

Formal analysis - Barış Kiriş (BK); Investigation - BK; Data collection - BK; Data processing - BK; Literature search – BK, Atakan Öngen (AÖ), Adem Yurtsever (AY); Writing – original draft – BK, AÖ, AY; Review & editing – BK, AÖ

Conflict of Interest Statement

The authors declare that there is no conflict of interest regarding the publication of this paper.

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References

[1] Qureshi, M. S., Oasmaa, A., Pihkola, H., Deviatkin, I., Tenhunen, A., Mannila, J., Minkkinen, H., Pohjakallio, M., & Laine-Ylijoki, J. (2020). Pyrolysis of plastic waste: Opportunities and challenges. *Journal of Analytical and Applied Pyrolysis, 152*, 104804.

[2] Miandad, R., Barakat, M. A., Aburiazaiza, A. S., Rehan, M., & Nizami, A. S. (2016). Catalytic pyrolysis of plastic waste: A review. *Process Safety and Environmental Protection*, 102, 822–838.

[3] Budsaereechai, K., Ngernyen, Y., & Hunt, A. J. (2019). Catalytic pyrolysis of plastic waste for fuel production: Low-cost bentonite catalysts. *Sustainable Energy & Fuels, 3*(3), 594–605. https://doi.org/10.1039/C8SE00432C

[4] Anuar Sharuddin, S. D., Abnisa, F., Wan Daud, W. M. A., & Aroua, M. K. (2017). Energy recovery from pyrolysis of plastic waste: Study on non-recycled plastics (NRP) data as the real measure of plastic waste. *Energy Conversion and Management, 148*, 925–934.

[5] Singh, R. K., & Ruj, B. (2016). Time and temperature depended fuel gas generation from pyrolysis of real world municipal plastic waste. *Fuel, 174*, 164–171.

[6] Dogu, O., Pelucchi, M., Van de Vijver, R., Van Steenberge, P. H. M., D'hooge, D. R., Cuoci, A., Mehl, M., Frassoldati, A., Faravelli, T., & Van Geem, K. M. (2021). The chemistry of chemical recycling of solid plastic waste via pyrolysis and gasification: State-of-the-art, challenges, and future directions. *Progress in Energy and Combustion Science, 84*, 100901.

[7] Zhang, X., Yan, C., Ma, Z., Li, H., Chen, G., & Wang, X. (2022). Insights into the co-pyrolysis kinetics and product mechanism of polyethylene, polypropylene, and their mixtures. *Journal of Analytical and Applied Pyrolysis, 164*, 105562.

[8] Wu, C., & Williams, P. T. (2010). Pyrolysis–gasification of plastics, mixed plastics and real-world plastic waste with and without Ni–Mg–Al catalyst. *Fuel, 89*(11), 3022–3032.

[9] Adrados, A., de Marco, I., Caballero, B. M., López, A., Laresgoiti, M. F., & Torres, A. (2012). Pyrolysis of plastic packaging waste: A comparison of plastic residuals from material recovery facilities with simulated plastic waste. *Waste Management, 32*(4), 826–832.

[10] Kusenberg, M., Zayoud, A., Roosen, M., Dao Thi, H., Seifali Abbas-Abadi, M., Eschenbacher, A., Kresovic, U., De Meester, S., & Van Geem, K. M. (2022). A comprehensive experimental investigation of plastic waste pyrolysis oil quality and its dependence on the plastic waste composition. *Fuel Processing Technology, 227*, 107090.

[11] Miandad, R., Barakat, M. A., Aburiazaiza, A. S., Rehan, M., Ismail, I. M. I., & Nizami, A. S. (2017). Effect of plastic waste types on pyrolysis liquid oil. *International Biodeterioration & Biodegradation, 119*, 239–252.

[12] Harussani, M. M., Saptoadi, H., Idris, A., & Yoshikawa, K. (2022). Pyrolysis of COVID-19 polypropylene waste: Kinetic study, char and oil characterization. *Journal of Environmental Chemical Engineering, 10*(3), 107390. https://doi.org/10.1016/j.jece.2022.107390

[13] Dai, L., Zhou, N., Lv, Y., Cheng, Y., Wang, Y., Liu, Y., Cobb, K., Chen, P., Lei, H., & Ruan, R. (2022). Pyrolysis technology for plastic waste recycling: A state-of-the-art review. *Progress in Energy and Combustion Science, 93*, 101021.

[14] Miandad, R., Rehan, M., Barakat, M. A., Aburiazaiza, A. S., Khan, H., Ismail, I. M. I., Dhavamani, J., Gardy, J., Hassanpour, A., & Nizami, A.-S. (2019). Catalytic Pyrolysis of Plastic Waste: Moving Toward Pyrolysis Based Biorefineries. *Frontiers in Energy Research, 7*, 27.

[15] Al-Salem, S. M., Antelava, A., Constantinou, A., Manos, G., & Dutta, A. (2017). A review on thermal and catalytic pyrolysis of plastic solid waste (PSW). *Journal of Environmental Management, 197*, 177–198. https://doi.org/10.1016/j.jenvman.2017.03.084

[16] Kalargaris, I., Tian, G., & Gu, S. (2017). The utilisation of oils produced from plastic waste at different pyrolysis temperatures in a DI diesel engine. *Energy, 131*, 179–185.

[17] Ryu, H. W., Kim, D. H., Jae, J., Lam, S. S., Park, E. D., & Park, Y.-K. (2020). Recent advances in catalytic co-pyrolysis of biomass and plastic waste for the production of petroleum-like hydrocarbons. *Bioresource Technology, 310*, 123473.

[18] Miandad, R., Barakat, M. A., Rehan, M., Aburiazaiza, A. S., Ismail, I. M. I., & Nizami, A. S. (2017). Plastic waste to liquid oil through catalytic pyrolysis using natural and synthetic zeolite catalysts. *Waste Management, 69*, 66–78.

[19] Ding, K., Liu, S., Huang, Y., Zhou, N., Peng, P., Wang, Y., Chen, P., & Ruan, R. (2019). Catalytic microwave-assisted pyrolysis of plastic waste over NiO and HY for gasoline-range hydrocarbons production. *Energy Conversion and Management, 196*, 1316–1325.

[20] Almeida, M. F., & Marques, M. M. (2016). Thermal and catalytic pyrolysis of plastic waste. In M. F. Almeida & M. M. Marques (Eds.), *Waste Biorefinery* (pp. 511–548). Elsevier. https://doi.org/10.1016/B978-0-12-802980-0.00019-4

[21] Wu, C., & Williams, P. T. (2010). Pyrolysis–gasification of plastics, mixed plastics and real-world plastic waste with and without Ni–Mg–Al catalyst. *Fuel, 89*(11), 3022–3032.

[22] Yao, D., Li, H., Dai, Y., & Wang, C.-H. (2021). Impact of temperature on the activity of Fe-Ni catalysts for pyrolysis and decomposition processing of plastic waste. *Chemical Engineering Journal, 408*, 127268.

[23] Odoi-Yorke, F., Agyekum, E. B., Rashid, F. L., Davis, J. E., & Togun, H. (2025). Trends and determinates of hydrogen energy acceptance, or adoption research: A review of two decades of research. *Sustainable Energy Technologies and Assessments*, *73*, 104159.

[24] Zhang, L., Han, K., Wang, Y., Zhu, Y., Zhong, S., & Zhong, G. (2023). A bibliometric analysis of Stirling engine and in-depth review of its application for energy supply systems. *Energy Reviews*, 100048.

[25] Göçer, F., & Büyüksaatçı Kiriş, S. (2023). A bibliometric analysis of quality control charts. *İstanbul Nişantaşı Üniversitesi Sosyal Bilimler Dergisi*, 11(2), 263-282. https://doi.org/10.52122/nisantasisbd.1256691

[26] Bastian, M., Heymann, S., & Jacomy, M. (2009, March). Gephi: an open source software for exploring and manipulating networks. In *Proceedings of the international AAAI conference on web and social media* (Vol. 3, No. 1, pp. 361-362).

[27] Van Eck, N., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *scientometrics*, *84*(2), 523-538.

[28] Liu, X., Zhang, J., & Guo, C. (2013). Full-text citation analysis: A new method to enhance scholarly networks. *Journal of the American Society for Information Science and Technology*, *64*(9), 1852-1863.

[29] Aria, M., & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of informetrics*, *11*(4), 959-975.

[30] Cobo, M. J., López-Herrera, A. G., Herrera-Viedma, E., & Herrera, F. (2011). Science mapping software tools: Review, analysis, and cooperative study among tools. *Journal of the American Society for information Science and Technology*, *62*(7), 1382-1402.

[31] Li, K., Rollins, J., & Yan, E. (2018). Web of Science use in published research and review papers 1997–2017: A selective, dynamic, cross-domain, content-based analysis. *Scientometrics*, *115*(1), 1-20.

[32] Li, P. F., Xu, Y., & Chen, Q. B. (2024). Global trends and research characteristics on CO2 capture and conversion from 2000 to 2023: A bibliometric review. *Sustainable Energy Technologies and Assessments*, *67*, 103836.

[33] Armenise, S., Wong, S. L., Ramírez-Velásquez, J. M., Launay, F., Wuebben, D., Ngadi, N., Rams, J., & Muñoz, M. (2021). Plastic waste recycling via pyrolysis: A bibliometric survey and literature review. *Journal of Analytical and Applied Pyrolysis, 158*, 105265.

[34] Gonzalez-Aguilar, A. M., Pérez-García, V., & Riesco-Ávila, J. M. (2023). A thermo-catalytic pyrolysis of polystyrene waste review: A systematic, statistical, and bibliometric approach. *Polymers, 15*(6), 1582.

[35] Klippel, M. S., & Martins, M. F. (2022). Physicochemical assessment of waxy products directly recovered from plastic waste pyrolysis: Review and synthesis of characterization techniques. *Polymer Degradation and Stability, 204*, 110090.

[36] Ayub, Y., & Ren, J. (2024). Revealing the synergistic effect of feedstock compositions and process parameters in co-pyrolysis: A review based on bibliometric analysis and experimental studies. *Journal of Cleaner Production, 459*, 142540.

[37] Chang, Y. H., Chong, W. W. F., Liew, C. S., Wong, K. Y., Tan, H. Y., Woon, K. S., Tan, J. P., & Mong, G. R. (2025). Unveiling the energy dynamics of plastic and sludge co-pyrolysis: A review and bibliometric exploration on catalysts and bioenergy generation potential. *Journal of Analytical and Applied Pyrolysis, 186*, 106885.

[38] Sivan, D., Zafar, S., Rohit, R. V., Raj, V. R., Satheeshkumar, K., Raj, V., Moorthy, K., Misnon, I. I., Ramakrishna, S., & Jose, R. (2024). Towards circularity of plastics: A materials informatics perspective. *Materials Today Sustainability, 28*, 101001.

[39] Nabgan, W., Ikram, M., Alhassan, M., Owgi, A. H. K., Van Tran, T., Parashuram, L., ... & Nordin, M. L. (2023). Bibliometric analysis and an overview of the application of the non-precious materials for pyrolysis reaction of plastic waste. *Arabian Journal of Chemistry*, *16*(6), 104717.

[40] Wong, S. L., Mong, G. R., Nyakuma, B. B., Ngadi, N., Wong, K. Y., Hernández, M. M., ... & Chong, C. T. (2022). Upcycling of plastic waste to carbon nanomaterials: a bibliometric analysis (2000–2019). *Clean Technologies and Environmental Policy*, *24*(3), 739-759.

[41] Ragaert, K., Delva, L., & Van Geem, K. (2017). Mechanical and chemical recycling of solid plastic waste. *Waste Management, 69*, 24–58.

[42] Sharuddin, S. D. A., Abnisa, F., Daud, W. M. A. W., & Aroua, M. K. (2016). A review on pyrolysis of plastic wastes. *Energy conversion and management*, *115*, 308-326.

[43] Li, J., Liu, H., & Chen, J. P. (2018). Microplastics in freshwater systems: A review on occurrence, environmental effects, and methods for microplastics detection. *Water research*, *137*, 362-374.

[44] Vollmer, I., Jenks, M. J., Roelands, M. C., White, R. J., Van Harmelen, T., De Wild, P., ... & Weckhuysen, B. M.

(2020). Beyond mechanical recycling: giving new life to plastic waste. *Angewandte Chemie International Edition*, *59*(36), 15402-15423.

[45] Al-Salem, S. M., Antelava, A., Constantinou, A., Manos, G., & Dutta, A. (2017). A review on thermal and catalytic pyrolysis of plastic solid waste (PSW). *Journal of environmental management*, *197*, 177-198.

[46] Ellis, L. D., Rorrer, N. A., Sullivan, K. P., Otto, M., McGeehan, J. E., Román-Leshkov, Y., ... & Beckham, G. T. (2021). Chemical and biological catalysis for plastics recycling and upcycling. *Nature Catalysis*, *4*(7), 539-556.

[47] Panda, A. K., Singh, R. K., & Mishra, D. K. (2010). Thermolysis of waste plastics to liquid fuel: A suitable method for plastic waste management and manufacture of value added products—A world prospective. *Renewable and Sustainable Energy Reviews*, *14*(1), 233-248.

[48] Miandad, R., Barakat, M. A., Aburiazaiza, A. S., Rehan, M., & Nizami, A. S. (2016). Catalytic pyrolysis of plastic waste: A review. *Process Safety and Environmental Protection*, *102*, 822-838.

[49] Thiounn, T., & Smith, R. C. (2020). Advances and approaches for chemical recycling of plastic waste. *Journal of Polymer Science*, *58*(10), 1347-1364.

[50] Wong, S. L., Ngadi, N., Abdullah, T. A. T., & Inuwa, I. M. (2015). Current state and future prospects of plastic waste as source of fuel: A review. *Renewable and sustainable energy reviews*, *50*, 1167-1180.