Journal of Oil Palm Research
DOI: https://doi.org/10.21894/jopr.2026.0038

GLOBAL RESEARCH TRENDS ON PALM OIL FUEL ASH (POFA) FROM 1995 TO 2025: A BIBLIOMETRIC ANALYSIS

WAFI MUFADHAL[1*]; APRILINA PURBASARI[1] and HADIYANTO[1]

ABSTRACT

Palm oil fuel ash (POFA) is a palm oil industry waste product, estimated to be generated at approximately 0.006 tonnes for every tonne of fresh fruit bunches (FFB). The continually increasing quantity of POFA is not matched by appropriate waste management or utilisation. Although many previous studies have utilised POFA, further research development is difficult because there is no comprehensive summary, review, or identification of previous research to determine research gaps and future opportunities. Therefore, this study conducts a bibliometric analysis of POFA using VOSviewer to identify current conditions and research gaps. The bibliometric analysis was sourced from the Scopus database with the keyword "Palm Oil Fuel Ash (POFA)" from 1995 to 2025. The results of the analysis show an increasing trend in POFA research over the past 10 years. These studies are dominated by Malaysian researchers, with the majority of POFA utilisation being as a mixture in concrete, cement and mortar. There are research opportunities for several of the largest palm oil producing countries such as Indonesia, Thailand, and Colombia, which have seen little research conducted. Research opportunities regarding POFA may include review articles, life cycle assessment (LCA), optimisation, economic analysis and commercialisation, particularly in cement, concrete, mortar, soil stabilisation, adsorbents and asphalt.

Keywords: bibliometric analysis, palm oil fuel ash, palm oil industry waste, VOSviewer, waste utilisation.

Received: 22 January 2026; **Accepted:** 24 June 2026; **Published online:** 15 September 2026.

INTRODUCTION

The global palm oil industry continues to experience rapid growth to this day, particularly in recent years. Its widespread use and low price have made palm oil the primary target in the vegetable oil market, accounting for 36.43% of total global vegetable oil consumption, followed by soybean oil (27.75%) and canola oil (13.56%) (Awoh et al., 2023; Ngan et al., 2022). The increasing interest and consumption by the global community will be in line with the annual rise in palm oil production. According to data from the United States Department of Agriculture (USDA), there has been a 3% annual increase in production over the past ten years. By 2025, global palm oil production was projected to reach 80.72 million tonnes. Production is dominated by countries in the Southeast Asian region. Among these countries, Indonesia is the world's largest producer, producing up to 46.7 million tonnes, followed by Malaysia with 20.2 million tonnes (USDA, 2025). This increase in production is expected to continue in line with the growth of the world's population. It is estimated that by 2050, the global population will reach 9.7 billion, while total palm oil production will be in the range of 93 to 156 million tonnes yr^{-1} (Murphy et al., 2021; Yaro et al., 2022).

The development of the palm oil industry has brought many positive impacts for producing countries, particularly in terms of the economy. In Indonesia, the palm oil industry contributes up to 3.5% of the national Gross Domestic Product (GDP) and has employed 16.2 million people (Anam et al., 2025). In Malaysia, the palm oil industry contributes 2.4% of the total GDP (Zachlod et al., 2025). According to 2023 data, 10% of the total workforce in Malaysia depends on the palm oil industry, consisting of 3 million workers and 500,000 smallholders (Mustapa, 2025). Alongside these positive impacts, there are significant issues that

[1] Department of Chemical Engineering,
Faculty of Engineering,
Universitas Diponegoro, Jl. Prof. Jacub Rais,
Semarang, Central Java, 50275, Indonesia.

* *Corresponding author e-mail: w.mufadhal@gmail.com*

need to be addressed, particularly concerning environmental problems for the sustainability of the industry. The main environmental issues in the palm oil industry include deforestation, loss of biodiversity, greenhouse gas (GHG) emissions, and the presence of process waste (Siagian et al., 2024). Among these issues, waste management is considered a key factor in achieving sustainability (Awoh et al., 2023). Based on the trend analysis conducted by Jamil and Asrol (2024), it is evident that the existence of by-products or waste from the palm oil industry is one of the main research issues in achieving sustainability.

The government, non-governmental organisations (NGOs), and relevant parties have in fact agreed on the creation of certification or joint regulations with the aim of addressing waste issues and achieving sustainability in the palm oil industry (Adwiyah et al., 2023). Among these are the Roundtable on Sustainable Palm Oil (RSPO) and the Sustainable Development Goals (SDGs). The RSPO was established in 2004 as an international non-profit association to regulate the palm oil industry by setting global standards and ensuring sustainable processes. There are seven principles and criteria (P&C) that have been established, one of which aims to utilise by-products from palm oil processing in accordance with applicable regulations (RSPO, 2024). According to data as of 8 January 2025, there are 6,106 active members from 105 countries and 505 certified palm oil industries with a total land area of 5,151,975 ha (Zachlod et al., 2025). In addition to RSPO certification, there is also a global sustainability target, namely the SDGs, which were agreed upon by the United Nations (UN) on 25–27 September 2015 (UN, 2015). One of the agreed targets is SDG 12, which concerns ensuring responsible consumption and production patterns. In general, the main aim of SDG 12 policy is to improve resource efficiency, reduce waste production and minimise the environmental impact of processes (Segovia-Hernández et al., 2023). Specifically, the target in point 12.5 states: "By 2030, substantially reduce waste generation through prevention, reduction, recycling, and reuse," with the success indicator being the recycling rate or the amount of material recycled at the national level (Gasper et al., 2019). Therefore, based on RSPO standards and these SDG targets, all forms of waste from palm oil processing should be minimised through prevention, reduction, recycling and reuse, thereby ensuring the sustainability of the industry.

One of the industrial wastes produced from the palm oil processing is palm oil fuel ash (POFA). Boiler ash waste or POFA is the ash waste generated from the combustion of biomass (empty bunches, fibres, and shells) occurring at temperatures between 800°C–1,000°C in the boiler (Huseien et al., 2022; Patah et al., 2025). This combustion is estimated to produce POFA at a rate of 0.005–0.006 t^{-1} of fresh fruit bunch (FFB) (Kahar et al., 2022; Supriatna et al., 2022). Meanwhile, based on the average capacity of palm oil processing industries (10–60 t FFB hr^{-1}), it is estimated to generate POFA waste of 65–394 kg (Rosyidi et al., 2022). According to available data, in Malaysia, the palm oil industry produces an average of 3 million tonnes of POFA yr^{-1}, Thailand averages more than 100,000 t yr^{-1} (Hasan et al., 2023) and Colombia produces as much as 28,620 t yr^{-1} (Zelaya et al., 2017). Meanwhile, in Indonesia, POFA waste production is estimated to reach 3.7 million tonnes yr^{-1} (Ismail et al., 2022). In fact, according to Liew et al. (2024), the global palm oil industry is estimated to produce 12 million tonnes of POFA waste annually.

The management of POFA waste is generally carried out merely by stockpiling it around the factory or placing it in open ponds. Such handling can in fact lead to various environmental problems, such as air, soil, and groundwater pollution (Abdulhaleem et al., 2025). POFA waste may take the form of PM2.5 particles (fine particles) and PM10 (coarse particles) (Shahidin et al., 2021), or very light dust, making it highly susceptible to being carried by the wind and becoming an air pollutant for the surrounding community. If POFA is inhaled into the respiratory system, it may cause carcinogenesis and lung disease (Demirboga & Farhan, 2022), due to its high silica content and the natural radioactivity of potassium ^{-40}K (Rosyidi et al., 2022). In addition, the presence of chemical content in the form of heavy metals can accumulate to form leachate. This leachate has the potential to contaminate surface water and groundwater, posing risks to aquatic ecosystems and human populations (Abuabdou et al., 2021). In addition to these hazard threats, it is known that the cost of constructing ash disposal sites (such as final disposal sites or ash ponds) requires a considerable expenditure. In developing countries, the cost is around USD5 t^{-1}, and in developed countries it can even reach USD50 t^{-1} (Foo & Hameed, 2009). Therefore, it can be concluded that there is an urgency regarding the utilisation of POFA waste due to the increase in the amount of POFA waste, the dangers arising from the physicochemical properties of POFA waste, improper handling of POFA waste, as well as the high cost of waste management.

Based on previous studies, the utilisation of POFA can be carried out and applied as construction materials (concrete, cement, mortar, porcelain, bricks, asphalt and paving blocks), active materials (adsorbents, catalysts, and membranes), and for soil stabilisation. The use of POFA as a construction material such as concrete, for example, was conducted by Umer et al. (2026) by mixing POFA and natural fibres to produce concrete with a tensile strength value of 86%. Other studies include the utilisation of POFA as cement (Rahman et al., 2024), mortar (Isa & Awang, 2023), porcelain (Jamo et al., 2022), clay bricks (Tjaronge & Caronge, 2021), asphalt (Hin et al., 2024), and paving blocks (Aisyah et al., 2024). The utilisation of POFA as an active material, for instance, has been applied in the adsorption of heavy metals in aquatic environments (Hamzah et al., 2025), lead(II) (Lim et al., 2022), palm oil mill effluent (POME) (Mustafa et al., 2022), free fatty acids (FFA) in used cooking oil waste (Zainal et al., 2024), methylene blue (Pelita et al., 2023), FFA in crude palm oil (CPO) (Sitohang et al., 2024), methane decomposition catalysts (Hanifa et al., 2022) and biodiesel catalysts in the transesterification process (Uba et al., 2024). The use of POFA in membranes includes polyvinylidene fluoride (PVDF) and POFA membranes for waste separation (Abuabdou et al., 2021) as well as hollow fibre membranes for water filtration (Tai et al., 2021). Meanwhile, the application of POFA in soil stabilisation can be seen in the stabilisation of residual soil and marine clay (Khasib et al., 2023), peat soil (Dwina et al., 2024), black cotton soil (Gopal & Chamberlin, 2023), clay soil (Nasution et al., 2023), tropical clay (Riascos et al., 2026) and tropical laterite soil (Ezreig et al., 2023).

From the explanation above, several previous studies have focused on the utilisation of POFA waste as the main subject of research. The development of the palm oil industry has driven an increase in studies aimed at optimising processes and achieving sustainability targets. Therefore, there is a need for a review article that can comprehensively summarise previous research. Nowadays, there are only a few review articles on the utilisation of POFA, such as reviews on the use of POFA in concrete (Hamada et al., 2023a), concrete and mortar (Sufian et al., 2025), cement (Liew et al., 2024), bricks (Mora-Ruiz et al., 2026) and adsorbent (Oyehan et al., 2022). However, there has not yet been a review article addressing the overall utilisation of POFA, whether in the form of narrative discussion, systematic review, meta-analysis, bibliometric analysis, or other types of review articles. To facilitate the development of research, a review article is needed to identify previous studies and thus reveal the gaps between them.

The field of bibliometrics was introduced in 1969 by Pritchard, Nalimov and Mulchenko (Padmalia, 2023). Bibliometrics is used as a systematic mapping strategy to ensure the depth of current knowledge and to accurately identify the actual conditions within a particular scope. Bibliometric analysis can be carried out using relevant data from literature and academic publications (Kartikowati, 2024). One of the tools that can be used to map bibliometric data analysis, and an example of a mapping tool is VOSviewer. VOSviewer is a scientometric application developed by Nees Jan Van Eck and Ludo Waltman from Leiden University in the Netherlands (Van Eck & Waltman, 2010). This application is based on a local movement algorithm that identifies relationships within networks of publications, citations, and keywords in a specific field. VOSviewer can utilise input from Web of Science, Scopus, and PubMed, with the output in the form of maps representing networks of keywords, publications, scientific journals, researchers, research organisations, and the countries of origin of researchers. The resulting network mapping can be linked in the form of co-author links, co-occurrence, citation, bibliographic coupling, or co-citation (Kirby, 2023).

Therefore, this study will present a bibliometric analysis using VOSviewer on POFA based on previous research articles obtained from the Scopus database. The research articles used as data cover the period from 1995 to 2025. The objectives of this research include: 1) Identifying research trends related to the utilisation of POFA, 2) determining the relationships between institutions, journals, countries and authors in research publications related to the utilisation of POFA, and 3) understanding the overview of topics and gaps in research publications related to the utilisation of POFA. This study is expected to serve as a source of information to identify the latest research as well as the gaps between studies related to the utilisation of POFA. Thus, it will provide understanding and a source of inspiration for prospects or opportunities related to future POFA research.

MATERIALS AND METHODS

Identification

This study was conducted using bibliometric analysis with the VOSviewer application (version 1.6.20) and Microsoft Excel (version 2603) to obtain a qualitative overview, create a bibliometric map, and process data. The data source used in this study is derived from the Scopus database due to its extensive coverage and common use as a research reference. The selected time span ranges from 1995 to 2025, or 30 years, as this research is the first to use bibliometric analysis in discussing previous studies related to the utilisation of POFA. Thus, bibliometric analysis is expected to be conducted from the first year of publication, namely 1995, to cover all related publications. Furthermore, the choice of a 30-year range was made so that more databases could be used, making the results more informative, as the minimum recommended number of databases for bibliometric analysis is 100 (Van Eck & Waltman, 2010).

Screening

Data collection was carried out from 7 to 14 December 2025 via the Scopus website (https://www.scopus.com/pages/home). The data search process began by entering the keyword in the TITLE-ABS-KEY menu as "Palm Oil Fuel Ash POFA" with a publication range from 1995 to 2025, resulting in a total of 756 documents. However, it turned out that some of the documents found were not focused on the discussion of POFA and did not use English as the global language. One way to obtain articles with a primary focus on POFA-related discussions is by restricting the keywords. According to Corrin et al. (2022), restricting keywords will produce more relevant search results, thus producing a stronger systematic review.

Therefore, keyword and language restrictions were applied to obtain more specific and unbiased data. Mandatory keywords were selected from all the available keywords in the "Keyword" menu, and those clearly related to the POFA topic were chosen. Among the available keywords, the mandatory keywords selected were "Palm Oil Fuel Ash", "Pofa", and "Palm Oil Fuel Ash (POFA)", as well as documents published in English. The search process then resulted in 415 documents relevant to the desired discussion.

Further filtering was then carried out by selecting the type of document classified as an article and the type of source classified as a journal. The selection of document type focusing on articles was done to eliminate documents in the form of conference papers, reviews, conference reviews, book chapters and retracted documents. Eliminating document types such as reviews, conference reviews and book chapters was intended to prevent data accumulation and overly broad discussions that could interfere with the analysis results. Meanwhile, the selection of source type focusing on journals was done to eliminate sources in the form of conference proceedings, book series and books. This is because the majority of journal sources provide longer, more in-depth discussions and are subject to stricter review before publication. In the end, a total of 272 documents were obtained and used as reference data for bibliometric analysis using the VOSviewer application.

The arrangement for searching articles using the Scopus database filter feature is as follows: (TITLE-ABS-KEY(Palm Oil Fuel Ash POFA) AND PUBYEAR > 1994 AND PUBYEAR < 2026 AND (LIMIT-TO (EXACTKEYWORD,"Palm Oil Fuel Ash") OR LIMIT-TO (EXACTKEYWORD,"POFA") OR LIMIT-TO (EXACTKEYWORD,"Palm Oil Fuel Ash (POFA)")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE,"j")) AND (LIMIT-TO (DOCTYPE,"ar"))).

Data Extraction and Analysis

Based on *Figure 1*, the diagram illustrates the mechanism for conducting the document screening process to be used in the bibliometric analysis. After reviewing the final 272 documents, it is evident that these documents are in-depth, accurate, and relevant to the main discussion topic, namely POFA. Therefore, all 272 documents are deemed suitable and will be used as sample data in the bibliometric analysis using VOSviewer. These documents will be mapped and identified by trends, relationships between authors, countries, journals, institutions and keywords found in each document.

RESULTS AND DISCUSSION

Characteristics of Publication Trends

Based on a search of articles related to POFA within the period 1995–2025 and filtering using keywords, language, type and document source, a total of 272 published research documents were obtained. These 272 documents were used to examine the publication trends with related keywords for each year. The results are presented as a graph showing the trend in the number of publications with related keywords for each year, as shown in *Figure 2*.

Based on *Figure 2*, it is known that research related to POFA has relatively increased in recent years. The first publication occurred in 1995, conducted by Sumadi and Hussin (1995), which discussed the utilisation of POFA as an alternative material for cement mixtures in the production of concrete and mortar. In 1997 and 2004, there was only one document each, with the main topic being the use of POFA as a material that can replace Portland cement (Awal & Hussin, 1997; Sata et al., 2004). However, in the following years, no publications related to POFA were found until they reappeared in 2007 with two documents. Then, in 2008 and 2009, no publications related to POFA were found again. Therefore, between 1995 and 2009, there were only five documents related to POFA from the sample data used. In the era up to 2009, it is known that the majority of research focus on the palm oil industry was on agricultural, chemical and medical science research. Agricultural research focused on ways to improve the cultivation and yield of oil palm, such as studies on soil nutrition, fertilisers, tree growth, fruit productivity, tree health, pest control and others. Chemical research was focused on processing, oil refining, and the processes of final products and their derivatives. Meanwhile, medical science research generally concerned the health impacts of palm oil products and industrial occupational safety (De Hoop & Van Der Vleuten,

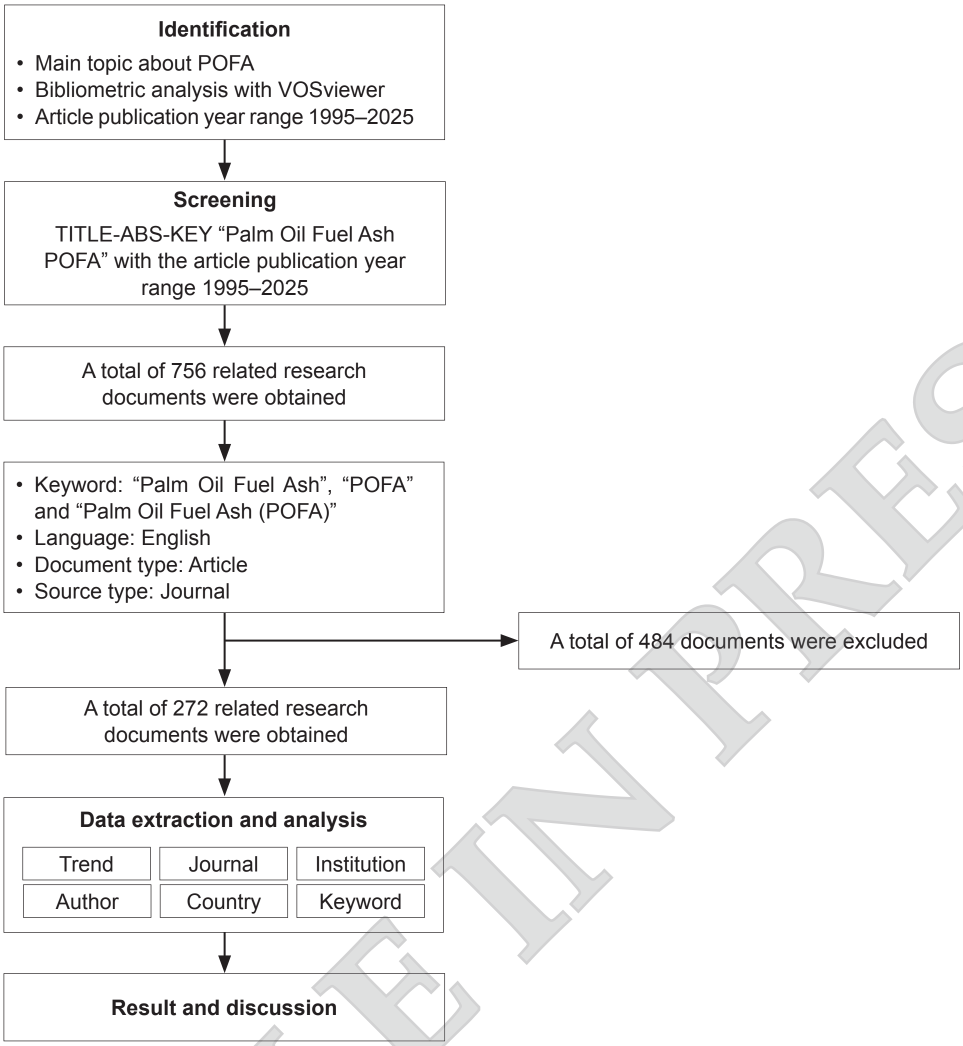

Figure 1. Research methodology flowchart.

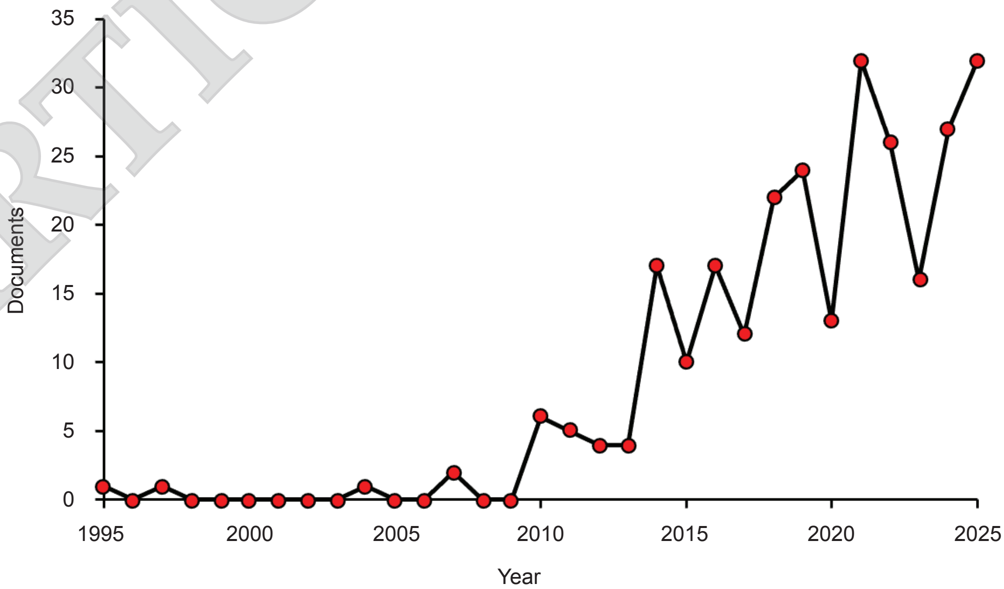

Figure 2. Annual publications about palm oil fuel ash (POFA) in 1995–2025.

2022). In the early 2000s, public interest in consuming palm oil products was at 22.23 million tonnes, still below the consumption of soybean oil products, which stood at 25.63 million tonnes (Ritchie, 2021). According to an analysis conducted by Ngan et al. (2022), publications on environmental sustainability in the palm oil industry began to increase in early 2008, reaching around 2,000 documents. Meanwhile, research by De Hoop and Van Der Vleuten (2022), found that up until 2005, there were only about 60 documents using the keywords "palm oil" and "sustainability". Furthermore, publications with the keyword "sustainability" were dominated by a focus on "climate action" issues resulting from oil palm plantation cultivation. Therefore, the lack of research related to environmental sustainability or waste management in the palm oil industry aligns with the limited number of documents discussing POFA.

At the beginning of 2010, the number of publications related to POFA experienced a significant increase, reaching a total of 6 documents. This was followed in 2011 by 5 documents, and then in 2012 and 2013, there were 4 documents each year. A surge in publications related to POFA occurred in 2014, with a total of 17 documents. During the period from 2010 to 2014, global production and consumption of palm oil began to rise. In 2013, global palm oil production reached 55.7 million tonnes, with the main sources being Indonesia and Malaysia, contributing 26.70 and 21.70 million tonnes respectively (Rifai et al., 2014). The increase in palm oil consumption was partly due to the emergence of obligations and regulations regarding "green energy" in the form of biofuel. According to data from 2013, the main source of biofuel was palm oil, accounting for 36.1% (Rifai et al., 2014). During that period, there was a regulation implemented by European countries, namely RED-2009/28/EC, which stipulated the obligation to use 10% biofuel in vehicle fuel (European Union, 2009). In Indonesia, Susilo Bambang Yudhoyono, as the sixth president, pledged that Indonesia would reduce GHG emissions by up to 26%, a commitment made during the G20 meeting in Pittsburgh in 2009 (Astari et al., 2025). The method employed was the issuance of Regulation of the Minister of Energy and Mineral Resources No. 25 of 2013 concerning the obligation to use 10% biofuel (Saputra et al., 2021). However, the increase in palm oil production and consumption has begun to raise concerns about the impact of the palm oil industry on ecosystems and biodiversity. For example, in Malaysia, data shows that from 2005 to 2013, 69% of deforestation events were caused by the expansion of palm oil (Zachlod et al., 2025). In Indonesia, from 2000 to 2010, deforestation occurred over a total area of 15 million hectares, with 11% attributed to the palm oil industry (Pye, 2019). The rise in production, consumption, and environmental concerns has led to a rapid increase in research and development in the palm oil industry related to environmental sustainability, reaching around 5,000 documents by 2014 (Ngan et al., 2022). According to the bibliometric analysis conducted by Hansen et al. (2015), research publications related to the sustainability of the palm oil industry are predominantly focused on the topic of "technology and residual use". The study identified a total of 109 documents concerning "technology and residual use", with 21% concentrating on liquid waste and 79% on solid waste (fronds, trunks, empty fruit bunches, fibre, kernel and boiler ash). Therefore, the increase in the number of such publications is also reflected in research related to POFA, as shown by the graphical data obtained in this study.

Until 2019, there was a continuous increase in publications related to POFA, although there was some fluctuation due to a decrease in the number of publications in 2017. In 2019, there were 24 documents discussing POFA. During the period from 2015 to 2019, countries around the world began to strictly regulate industrial policies to achieve sustainability. Several specific policies related to the palm oil industry include the Indonesian Sustainable Palm Oil (ISPO), Malaysian Sustainable Palm Oil (MSPO), and Europe Sustainable Palm Oil (ESPO). The ISPO was established in March 2011 by the Indonesian government through the Ministry of Agriculture. The main objective of ISPO is to ensure that laws and regulations related to the palm oil industry can be enforced through sustainability certification (Sylvia et al., 2022). The MSPO was established in 2013 using the MS 2530:2013 series standard (Michida, 2023). The MSPO set a deadline of 31 December 2019 for all palm oil industries in Malaysia to comply with national standards to meet sustainability aspects. Some of the main MSPO regulations include aspects of environmental safety, social responsibility, and process safety within the palm oil industry (Naidu & Moorthy, 2021). ESPO was agreed upon in 2015 through the Amsterdam Palm Oil Declaration by seven European countries, namely Denmark, France, Germany, Italy, the Netherlands, Norway, and the United Kingdom (Michida, 2023). The ESPO policy contains the obligation to use 100% palm oil from industries certified by RSPO before 2020 to achieve sustainability (European Palm Oil Alliance [EPOA], 2019). Broadly speaking, the policies of each country or region (ISPO, MSPO, ESPO and others) share similar principles with the RSPO policy as a global certification. One of these shared principles relates to environmental safety management. As per the RSPO vision, which is the 3Ps: People, Planet, and Prosperity. The "Planet" vision contains policies that regulate environmental sustainability by reusing waste, by-products, and residues from the palm oil processing industry. The implementation of these policies and certifications will lead to increased research and publications related to the sustainability of the palm oil industry, particularly in environmental sustainability. As seen in the study by Yadollahi et al. (2025), bibliometric analysis shows that between 2016 and 2019 there was a surge in palm oil publications using the keywords "challenges", "deforestation", "management", and "impact". These results are in line with the increase in publications that also occurred from research related to POFA between 2015 and 2019, because of the implementation of regulations and certifications in various countries or regions.

In the following year, there was a significant decline in research publications related to POFA. In 2020, there were only 13 research documents concerning POFA. Although there was a notable increase in 2021, publications related to POFA once again experienced a decline up to 2023. One of the causes of this decrease in publications was the COVID-19 pandemic. The pandemic affected the number of publications, which dropped across various topics in the Scopus database. According to research conducted by Raynaud et al. (2021), there was an average reduction in the total number of research publications, from an average of 28–22 in June 2020. Other studies have also stated that the COVID-19 pandemic has had a negative impact in terms of both quantity and quality on research in the fields of science and engineering (Yang & Li, 2024).

Subsequently, in 2024, there was a rapid increase in publications related to POFA, with 32 documents. Similarly, in the following year, there were 32 publication documents related to POFA in 2025. The trend shown by the graph indicates that issues in achieving environmental sustainability, one of which concerns the management of POFA waste, have begun to receive focus in research and development. With the continuously increasing quantity but inadequate management, research related to the utilisation of POFA has started to be developed. Furthermore, the dangers posed by POFA to the environment, ecosystem, and surrounding communities have heightened the urgency for POFA utilisation. Research related to POFA is expected to continue increasing in line with the development of the palm oil industry worldwide. The rising demand and consumption of palm oil, accompanied by increasingly stringent regulations, indicate that research on POFA waste will continue to increase and develop.

Journal Analysis

Based on *Table 1*, the top 10 journals with the highest number of article documents related to POFA in the Scopus database can be seen. The impact factor (IF) column is used as a metric to determine how frequently a journal's articles are cited within a certain period (Shah et al., 2024). Journals with high IF score will increase the visibility and number of citations of the article (Tahamtan et al., 2016). The Quartile (Q) score column can serve as a reference to assess the quality of a journal in comparison with other journals in a particular field. This score provides information regarding the citation performance and ranking of the journal compared to others. For example, if the sample journal is Q1, it means that the journal is ranked within the top 25% based on its impact factor among other journals in its field (Asan & Aslan, 2020). Meanwhile, the H-Index column is used to measure the reputation of a journal based on productivity and impact through citations to that journal (Anggoro et al., 2025).

TABLE 1. JOURNALS ANALYSIS OF PALM OIL FUEL ASH (POFA)

Rank	Journals	Documents	Citations	IF	Q score	H-index	Contributions (%)
1	Construction and Building Materials	39	3,539	8.0	Q1	293	14.338
2	Journal of Cleaner Production	10	851	10.0	Q1	354	3.676
3	Journal of Materials in Civil Engineering	10	483	3.0	Q1	149	3.676
4	Journal of Building Engineering	9	368	7.4	Q1	114	3.308
5	Jurnal Teknologi	8	42	0.6	Q3	38	2.941
6	International Journal of Integrated Engineering	7	50	0.6	Q3	23	2.573
7	Case Studies in Construction Materials	6	306	6.6	Q1	77	2.205
8	Materials	6	191	3.2	Q2	191	2.205
9	Innovative Infrastructure Solutions	6	26	2.5	Q2	35	2.205
10	Sustainability Switzerland	5	107	3.6	Q1	207	1.838

Note: IF - impact factor; Q - quartile.

Based on the ranking of the top 10 journals, it is known that there is a variation in journal categories according to citation impact (quartile), ranging from Q1, Q2 to Q3. The journal Construction and Building Materials (IF = 8.0; Q1) is the journal with the highest number of articles related to POFA, with a total of 39 documents, followed by the Journal of Cleaner Production (IF = 10.0; Q1) with 10 documents, and the Journal of Materials in Civil Engineering (IF = 3.0; Q1) with 10 documents. Based on the number of citations, the journal Construction and Building Materials has the highest number of citations, with 3,539 citations and a contribution percentage of 14.338% of the total sample documents. The second rank is held by the Journal of Cleaner Production, with 851 citations and a contribution percentage of 3.676%. This is followed by the Journal of Materials in Civil Engineering, with 483 citations and a contribution percentage of 3.676%. Q1 journals, including Construction and Building Materials, Journal of Cleaner Production, Journal of Materials in Civil Engineering, Journal of Building Engineering, Case Studies in Construction Materials, and Sustainability Switzerland, tend to have a higher number of citations accompanied by a high IF score. In comparison, Q2 and Q3 journals, such as Jurnal Teknologi, International Journal of Integrated Technology, Materials, and Innovative Infrastructure Solutions, show a very low number of citations, which is also accompanied by a low IF score. According to Tahamtan et al. (2016), the main factors influencing the number of citations include the journal's IF score, international collaboration, and the number of authors of the article.

It is known based on *Figure 3*, that the majority of the top 10 journals publishing POFA share the same field of focus, namely "engineering", "material science", and "environmental science". The field of "engineering" is the primary focus because the discussion of POFA is inseparable from the discussion of the palm oil industry. Furthermore, POFA can be included in the field of "material science" as it can be classified as a fly ash/pozzolan material in accordance with the requirements of ASTM C618 (ASTM International, 2019). POFA can be categorised as class F, with its major chemical composition consisting of silica-alumina-iron (Lin et al., 2024). Meanwhile, the presence of journals focusing on "environmental science" is because discussions regarding the environmental hazards of POFA often serve as the background for research in several previous studies.

Country Contributions

Bibliometric analysis using "co-authorship" was carried out employing "country" as the unit of analysis. A total of 38 countries have contributed to the production of articles related to POFA from 1995 to 2025. As shown in *Figure 4*, circles of larger size indicate a greater number of article publications by authors from those countries. The difference in circle colours represents the variation in research theme clusters based on the keywords used. Meanwhile, connecting lines between circles signify collaboration between authors from those countries.

Based on *Figure 4*, Malaysia is the country with the largest circle positioned at the centre, indicating that Malaysia is the largest contributor to research related to POFA. In terms of inter-country author

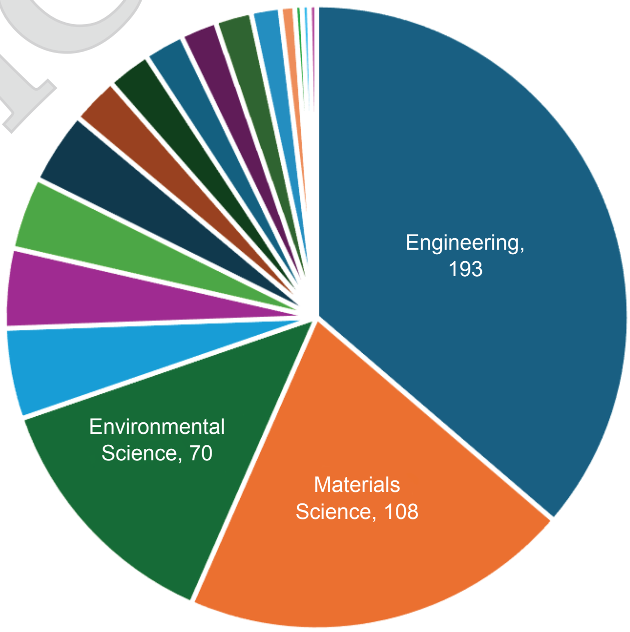

Figure 3. Documents by subject area.

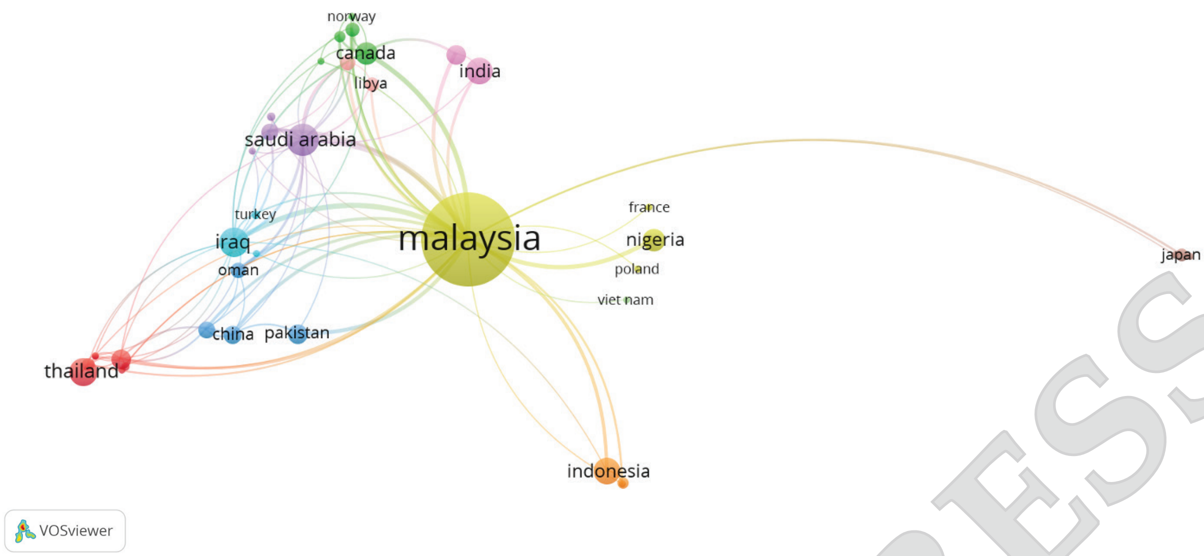

Figure 4. Country contributions analysis of palm oil fuel ash (POFA).

collaboration, Malaysia has lines connecting to 35 out of the total 38 countries, demonstrating Malaysia's central role in POFA-related research. Collaboration between Malaysia and Saudi Arabia shows a strong relationship among authors of POFA articles, as evidenced by the presence of a thick connecting line between the two countries.

The increase in palm oil production in Malaysia over the past ten years has been only 0.69%, with production recorded at 18.9 million tonnes in 2016 and 20.2 million tonnes in 2025 (USDA, 2025). Production growth has tended to stagnate, but when compared to other producing countries such as Indonesia, Thailand and Colombia, there has been a significant increase of 3% over the past 10 years. Stable production indicates that the development focus of the palm oil industry in Malaysia is no longer on land expansion but rather on quality improvement. Since the implementation of the MSPO in 2015, more than 90% of the palm oil industry in Malaysia has been MSPO certified (Yeoh et al., 2025). The application of standards began with MS 2530:2013 and was later updated to the more specific MSPO 2.0 or MS 2530:2022 standard. There are even more specific standards regulating the presence of biomass or waste from the palm oil processing industry, as found in MS 2751:2022, demonstrating Malaysia's seriousness in addressing environmental issues and achieving sustainability. According to Aziz et al. (2025), the conversion of biomass into environmentally friendly energy and value-added products has been a focus of attention in Malaysia for several decades. Strict and binding regulations, as well as government support, have led to an increase in research and publications on palm oil, one of which is research related to POFA as one of the industrial wastes.

It is further observed that the second largest circle is held by Saudi Arabia, followed by Iraq, Thailand and Indonesia. As the world's largest palm oil producer, publications related to POFA by Indonesian researchers are still not particularly significant. Although the ISPO certification has been established, in practice there are often loopholes in regulations, breaches of rules, and inadequate waste management (Judijanto, 2026). Ideally, ISPO certification should encourage the industry to manage and utilise waste in the interest of environmental sustainability. However, conflicts of interest, overlapping regional and national regulations, as well as regulatory ambiguities, hinder the implementation of ISPO certification (Choiruzzad et al., 2021). For example, the Job Creation Law Articles 110A and 110B contain a "legalisation" mechanism for palm oil industries operating without permits, which contradicts Law No. 41 of 1999 on the prohibition of illegal use of forest areas. Other issues include land ownership conflicts, environmental permits (AMDAL and B3), plantation business permits, and Right to Cultivate. The suboptimal implementation of ISPO has resulted in research and development in Indonesia's palm oil industry becoming varied.

It is known that Malaysia has a very significant contribution to the number of articles related to POFA, with a total of 212 documents or 77.941% of the overall total, as shown in *Table 2*. Due to this substantial research contribution, issues or research topics related to POFA tend to focus more on problems and cases specific to Malaysia. The second country with the highest number of articles is Saudi Arabia, with a total of 26 documents or 9.558% of the overall total. Next, the highest number of articles related to POFA is followed by Iraq (22 documents), Thailand (19 documents) and

Indonesia (18 documents). In terms of citations, Malaysia also ranks first with a total of 7,751 citations, followed by Thailand (1,530 times), Saudi Arabia (987 times) and Iraq (818 times). However, Indonesia appears to have a relatively low number of citations, namely 187 times. This indicates that these research articles have a slightly different focus of discussion compared to the majority. This fact can be seen from *Figure 4*, where it is evident that Indonesia's circle is positioned far on the periphery, indicating a difference in the focus of discussion from the majority of articles. Then, if grouped by country region, the Southeast Asian region (Malaysia, Thailand and Indonesia) is the area with the most articles related to POFA from 1995 to 2025, with a total of 249 documents. This is because the palm oil industry is a major industry in Southeast Asia, accounting for 87% of the world's total palm oil production (USDA, 2025). Meanwhile, in other regions such as America, Africa and Europe, there are only a few articles related to POFA.

TABLE 2. TOP 10 COUNTRIES WITH THE LARGEST PUBLICATIONS OF PALM OIL FUEL ASH (POFA)

Rank	Country	Documents	Citations	Contributions (%)
1	Malaysia	212	7,751	77.941
2	Saudi Arabia	26	987	9.558
3	Iraq	22	818	7.720
4	Thailand	19	1530	6.985
5	Indonesia	18	187	6.617
6	India	18	359	6.617
7	Canada	13	420	4.779
8	Nigeria	13	261	4.779
9	Australia	10	340	3.676
10	Bangladesh	10	204	3.676

Institution Cooperation

The aim of this analysis is to ascertain the overview and distribution of POFA publications in terms of institutions. It is known that out of a total of 272 documents related to POFA, there are 160 institutions that have facilitated this research. Based on *Table 3*, the top 10 institutions with the highest number of POFA-related publication articles can be seen. The first rank is Universiti Teknologi Malaysia with 51 documents, contributing 18.750% of the total. The second rank is Universiti Tun Hussein Onn Malaysia with 44 documents, contributing 16.236% of the total. This is followed by Universiti Sains Malaysia with 35 documents, contributing 12.867% of the total. Subsequently, ranks 4 to 7 are also held by institutions from Malaysia, namely Universiti Malaysia Pahang Al-Sultan Abdullah (32 documents), Universiti Malaya (28 documents), Universiti Putra Malaysia (13 documents), Universiti Kebangsaan Malaysia (11 documents), and in 10th place is Universiti Teknologi MARA (8 documents).

The results of this analysis indicate that one of the factors influencing research and development is the availability of facilities. These facilities may include infrastructure, technology, and even financial support from the government. In Malaysia, several institutions such as Universiti Malaya (ranked 82) and Universiti Teknologi Malaysia (ranked 86) are among the top 100 educational institutions in technology and science in Asia according to the QS World University Rankings. In addition, there is also funding support such as the collaboration between the Malaysia Palm Oil Board (MPOB) and Universiti Kebangsaan Malaysia (UKM), namely the MPOB–UKM Endowment Chair. The cooperation between institutions, the government (MPOB), and industry in Malaysia is a strategic collaboration known as the triple helix model (Etzkowitz & Leydesdorff, 1995). The triple helix is a model of synergy between the government, universities, and the business community to create new knowledge in the field of technology with the aim of supporting and enhancing innovation (Setianingrum et al., 2024). In fact, in recent years, Malaysia has experienced a shift towards the quadruple helix model,

TABLE 3. TOP 10 INSTITUTIONS WITH THE LARGEST PUBLICATIONS OF PALM OIL FUEL ASH (POFA)

Rank	Institution	Documents	Country	Contributions (%)
1	Universiti Teknologi Malaysia	51	Malaysia	18.750
2	Universiti Tun Hussein Onn Malaysia	44	Malaysia	16.236
3	Universiti Sains Malaysia	35	Malaysia	12.867
4	Universiti Malaysia Pahang Al-Sultan Abdullah	32	Malaysia	11.764
5	Universiti Malaya	28	Malaysia	10.294
6	Universiti Putra Malaysia	13	Malaysia	4.779
7	Universiti Kebangsaan Malaysia	11	Malaysia	4.044
8	King Mongkut's University of Technology Thonburi	11	Thailand	4.044
9	Jazan University	10	Saudi Arabia	3.676
10	Universiti Teknologi MARA	8	Malaysia	2.941

which involves the public in the development of innovation. This is done to realise the National Transformation 2050 (TN50), Industrial Revolution 4.0 (IR4.0), Shared Prosperity Vision (WKB 2030) and SDGs 2030 (Krishnan et al., 2025).

In eighth and ninth place, there are two other institutions, namely King Mongkut's University of Technology Thonburi (11 documents) from Thailand and Jazan University (10 documents) from Saudi Arabia. The limited variety of countries of origin for these institutions indicates a weakness in supporting innovation from the government, institutions, or related industries. Therefore, cooperation is needed in developing innovation among the relevant parties so that healthy competition between institutions can be established.

Author Contributions

Bibliometric analysis will be able to show the authors who have made the greatest contribution in terms of the number of research documents related to POFA. By selecting the "co-authorship" analysis with the unit of analysis as "author" in VOSviewer, an overview of the authors and the relationships between each author in research on the related topic can be obtained. Analysis of the 272 documents identified a total of 734 contributing authors. However, this author analysis only displays authors with at least 5 documents, to clearly show the relationships formed between them.

Based on *Figure 5* and *Table 4*, the results of the bibliometric analysis mapping can be seen, with authors who have a higher number of article publications represented by larger circles. The largest circle is Jumaat, Mohd Zamin, who has the most articles related to POFA, with a total of 18 documents (6.617% of the total). The second largest circle is Megat Johari, M. A. with a total of 16 documents (5.882% of the total), followed by Mohammad, Ismail Ismid Mohd with a total of 14 documents (5.147% of the total). Based on the bibliometric analysis, there is a concentration gap between Jumaat, Mohd Zamin (dark blue colour), Megat Johari, M. A. (green colour), and Mohammad, Ismail Ismid Mohd (red colour). This gap indicates a slight difference in the focus of discussion in their research. The research and publications conducted by Megat Johari, M. A. (green colour) and Mohammad, Ismail Ismid Mohd (red colour) tend to have the same keywords, namely "portland cement" or "ordinary portland cement". Meanwhile, Jumaat, Mohd Zamin (dark blue colour) tends to have the keywords "oil shale" and "fuels" because the majority of his research is conducted using a mixture of raw materials between fly ash and POFA. The fourth-ranked author, Alengaram, U. J. (13 documents), tends to have the same focus as Jumaat, Mohd Zamin. However, Alengaram's, U. J. node is not clearly visible because of overlapping in the mapping image. The fifth-ranked author, Hussin, Mohd Warid (12 documents), tends to have the same focus as Megat Johari, M. A. and Mohammad, Ismail Ismid Mohd. This is followed by Jaturapitakkul, C. (11 documents), Awang, Hanizam binti (11 documents), Mirza, Jahangir (10 documents), Zeyad, Abdullah M. (9 documents), and Jaya, Ramadhansyah Putra (9 documents).

Then, in terms of collaborative relationships between authors, as indicated by the lines connecting the circles, Mohammad, Ismail Ismid Mohd has the highest number of collaborative links with other authors, namely 41 connections and a total link strength of 67. The keywords used in publications by Mohammad, Ismail Ismid

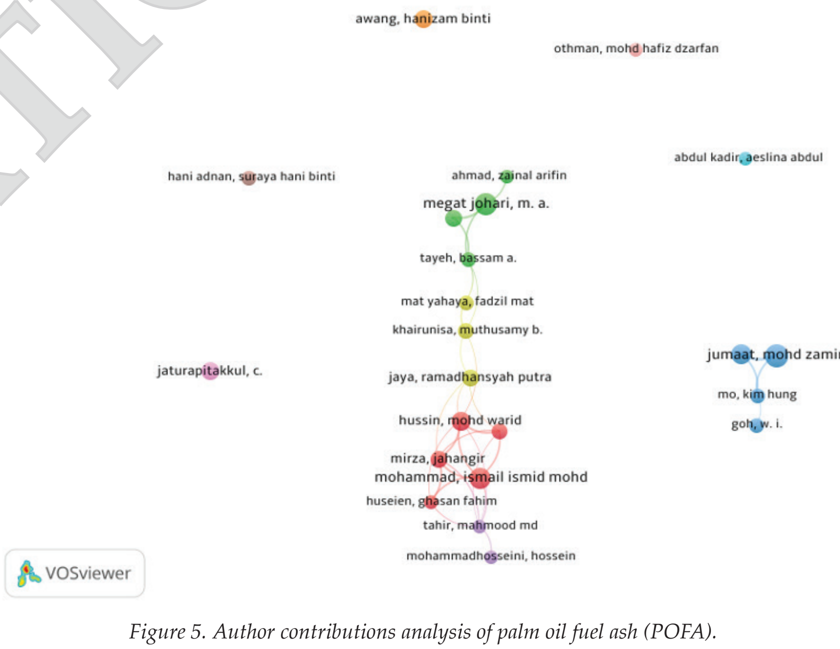

Figure 5. Author contributions analysis of palm oil fuel ash (POFA).

TABLE 4. TOP 10 AUTHORS WITH THE LARGEST PUBLICATIONS OF POFA

Rank	Author	Documents	Citations	Contributions (%)
1	Jumaat, Mohd Zamin	18	2,229	6.617
2	Megat Johari, M. A.	16	752	5.882
3	Mohammad, Ismail Ismid Mohd	14	596	5.147
4	Alengaram, U. J.	13	2,097	4.779
5	Hussin, Mohd Warid	12	674	4.411
6	Jaturapitakkul, C.	11	1,318	4.044
7	Awang, Hanizam Binti	11	169	4.044
8	Mirza, Jahangir	10	479	3.676
9	Zeyad, Abdullah M.	9	480	3.308
10	Jaya, Ramadhansyah Putra	9	125	3.308

Mohd are dominated by "palm oil fuel ash", "compressive strength", "palm oil", "POFA", and "ordinary Portland cement". This is followed by Jumaat, Mohd Zamin (59 total link strength; 25 connections) and Mirza, Jahangir (58 total link strength; 36 connections). This indicates that these authors frequently collaborate with others and have a strong thematic connection between the research articles they publish (Donthu et al., 2021).

Keywords Analysis

Keyword analysis in research articles aims to identify the focus of the discussion and research within the article. Keywords assist researchers and readers in understanding the main subject, scope, developments and research trends related to the topic (Matsimbe et al., 2022). Keyword analysis can reveal research focus trends by displaying the keywords of each research article used as a sample. This enables an overview of the development of research in terms of discussion topics and allows for the identification of gaps between studies by examining the relationships between keywords or research clusters.

Bibliometric analysis begins with selecting the "co-occurrence" analysis with unit analysis as "all keywords" in VOSviewer, after which an overview is obtained regarding keyword trends and the relationships between each keyword in research on the related topic. From a total of 272 articles used as data, there were 1,757 keywords. However, only 1,000 keywords with the best total link strength are displayed in the bibliometric analysis. Based on *Figure 6*, a total of 21 research clusters are formed, each represented by a different colour for each research cluster. Each research cluster can represent a different research area or focus. The results of the bibliometric analysis of POFA identified fiva main cluster.

Cluster 1 (97 keywords), represented in red, is the cluster with similarities in keywords related to the morphological characteristics and physicochemical properties of POFA material. Some of the keywords with a high frequency of occurrence are "compressive strength", "microstructure" and "scanning electron microscopy". Based on this cluster, it is evident that there are already a great number of articles discussing the morphological characteristics and physicochemical properties of POFA material. Furthermore, discussions regarding morphological characteristics and physicochemical properties are also very dominant and have extensive and strong connections with other keywords. The keyword "compressive strength" has up to 680 links with other keywords. According to Sufian et al. (2025), the process of identifying the characteristics and properties of POFA is a very necessary stage because the source of POFA and the initial handling given will greatly influence the properties and surface morphology of the material.

Cluster 2 (78 keywords), represented by dark green, is the cluster discussing the utilisation of POFA in the context of environmental sustainability. This can be seen from one of the most frequently appearing keywords, namely "sustainability" or "sustainable development". The position of the "sustainability" circle is quite central, indicating that this keyword is one of the main topics highly relevant to the majority of publications related to POFA. In this cluster, there is the keyword "oil shale", which appears 43 times. The appearance of this keyword is due to the presence of many documents that use mixtures or compare fly ash with POFA. The utilisation of POFA or fly ash will reduce one of the industrial wastes that can threaten ecosystems and cause environmental pollution. Among other keywords, POFA is utilised as a substitute material for ordinary Portland cement (OPC), which is linked as a solution for reducing carbon emissions, waste utilisation and the substitution of environmentally friendly materials.

Cluster 3 (72 keywords), represented by dark blue, is the cluster discussing the utilisation of POFA

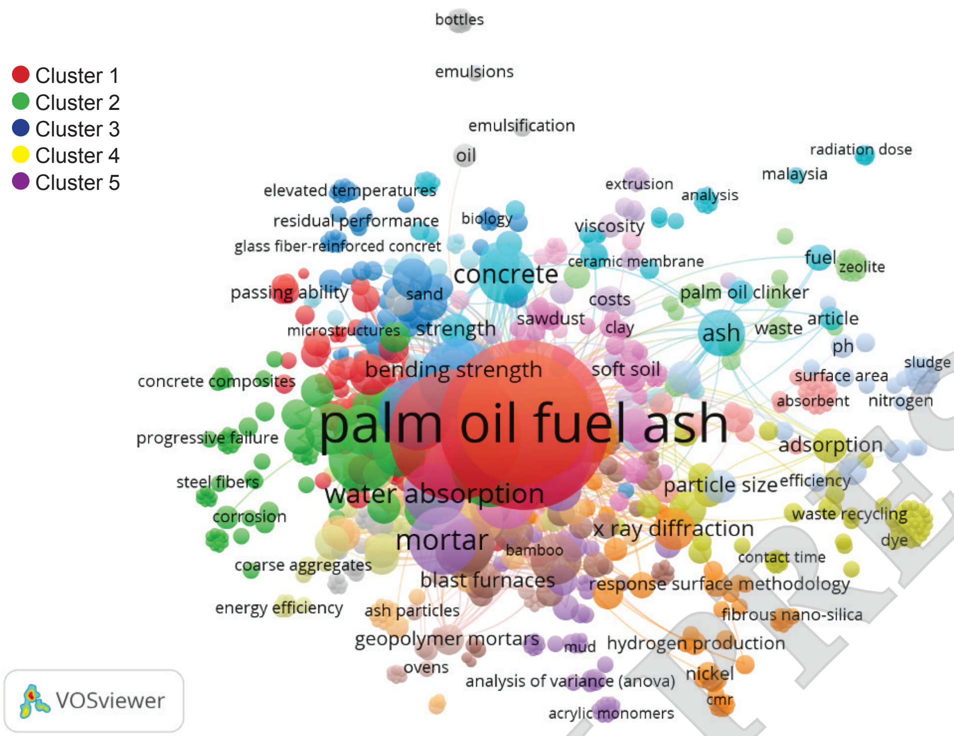

Figure 6. Keywords analysis of palm oil fuel ash (POFA).

in concrete and cement in relation to its source and properties. In this cluster, the keywords with the highest occurrences are “fuels” (47 times), “Portland cement” (38 times), and “cement replacement” (19 times). It is known that POFA is a residual material resulting from the combustion of biomass waste at high temperatures (800°C–1,000°C) in a boiler (Patah et al., 2025). The biomass is used as a fuel, replacing conventional fuels such as coal. Combustion at these high temperatures produces POFA in the form of black or dark-coloured ash, with particle sizes ranging from 30.8–62.5 nm, and a specific gravity between 1.81–2.60 (Demirboga & Farhan, 2022; Oyehan et al., 2022). Therefore, there are several publications related to the utilisation of POFA as a cementitious material, such as in Portland cement or pozzolanic cement, based on the source and properties of the POFA material.

Cluster 4 (69 keywords), represented by a dark gold colour, is the cluster discussing the utilisation of POFA as an adsorbent or for contaminant absorption. The dominant keywords in this cluster are “fly ash” and “adsorption”. It is known, based on its chemical composition, that POFA generally consists of SiO_2 (45%–65%) (Onsongo et al., 2025) along with other components such as Fe_2O_3, Al_2O_3, CaO, MgO, Na_2O, K_2O and SO_3 (Amran et al., 2021). With the dominance of silica-alumina, POFA can be regarded as a natural zeolite which has high potential for absorbing inorganic contaminants, organic matter and colour impurities (Oyehan et al., 2022). According to Xu et al. (2025), a high Si/Al ratio causes POFA material to tend to be hydrophobic or non-polar. In addition, the surface morphology of POFA contains pores, has a large volume capacity, and a high surface area due to the presence of silica components (Senila & Cadar, 2024). Several other keywords indicate examples of applications for POFA adsorbents that have been carried out by previous research, for example the keywords “dyes”, “effluent decolourisation”, “manganese removal”, “textile wastewater”, and “water pollution”.

Cluster 5 (64 keywords), represented by dark purple, is the cluster discussing the utilisation of POFA as a mortar material, including testing and modification. Some of the dominant keywords in this cluster are “mortar”, “water absorption”, and “porosity”. The quality and durability of mortar are greatly influenced by the material’s ability to resist water penetration, which is closely related to its porosity and water absorption properties (Hossain et al., 2024). Therefore, several studies have carried out modifications, as indicated by keywords such as “methyl methacrylate”, “polyethylene terephthalate”, “polymer composite”, and “taguchi method”.

Based on *Table 5*, the top 20 keywords used in research articles related to POFA can be seen. The keyword "palm oil fuel ash" (209 documents), as the main topic of discussion, ranks first. There are several other main keywords, such as "POFA" with 50 documents and "palm oil fuel ash (POFA)" with 31 documents. Furthermore, there are several general keywords, such as "palm oil" (128 documents), "fuel ash" (62 documents), "fuels" (47 documents), "oil shale" (43 documents), and "fly ash" (29 documents), as POFA waste is the result of biomass combustion in boilers, which poses an environmental sustainability issue for the palm oil industry. In third place is the keyword "compressive strength", which is one of the tests that can be carried out to determine the quality of construction materials. Several other keywords in *Table 5*, such as "water absorption", "microstructure", "durability" and "scanning electron microscopy" also indicate various testing methods to identify the properties or characteristics required for the utilisation of POFA as a construction material. It can therefore be seen that the majority of keywords related to the utilisation of POFA are associated with its use as a construction material, for example in the keywords "portland cement", "concretes", "mortar", "cement", "geopolymer", "binder", and "concrete". This demonstrates that the primary use of POFA is as a construction material, with the aim of improving quality due to the properties and characteristics possessed by POFA material.

TABLE 5. TOP 20 KEYWORDS RELATED TO PALM OIL FUEL ASH (POFA) PUBLICATIONS

Rank	Keyword	Documents	Total link strength
1	Palm oil fuel ash	209	2,745
2	Palm oil	128	2,658
3	Compressive strength	124	1,993
4	Fuel ash	62	1,189
5	Pofa	50	490
6	Fuels	47	945
7	Oil shale	43	942
8	Portland cement	38	724
9	Concretes	33	677
10	Mortar	33	534
11	Cements	31	623
12	Palm oil fuel ash (POFA)	31	313
13	Fly ash	29	648
14	Water absorption	28	450
15	Binders	27	507
16	Microstructure	26	462
17	Durability	25	377
19	Geopolymers	23	528
20	Concrete	23	321

PROSPECTS AND CHALLENGES

Challenges in Managing POFA Waste for Palm Oil Producing Countries

Based on a bibliometric analysis using "country" as the unit of analysis, it is evident that Malaysia is the country with the highest contribution, accounting for 212 documents or 77.941% of the total documents. From this data, it must be acknowledged that the majority of discussions and issues related to POFA are based on the conditions or circumstances occurring in Malaysia. With a high number of publications, there will naturally be a variety of innovations in the utilisation of POFA waste, ultimately achieving environmental sustainability. However, several other major producing countries such as Indonesia (18 documents), Thailand (19 documents) and Colombia (1 document) still have minimal publications related to POFA. Therefore, challenges will arise due to the threat of increasing amounts of POFA waste because of the significant rise in palm oil production (Indonesia, Thailand and Colombia), which has increased by 3% over the past ten years. The urgency of these challenges is further heightened by the improper management of POFA waste, such as its disposal in open fields, which can endanger the environment and surrounding ecosystems. According to Khatrinatasa (2025), weak management in handling process waste can be attributed to several factors, namely limited technology, poor supervision, or inadequate institutional policies. Thus, the government has a significant role and responsibility in facing these challenges. According to United Nations Development Programme (UNDP, 1997), the principles of good governance include having clear regulations and facilitating the needs of society. In this context, it is necessary to establish specific regulations to govern the industry, as Malaysia has done by mandating MSPO certification for every palm oil industry. Strict regulations will lead to an increase in research and publications that are both practical and solution-oriented in addressing the issues faced. Furthermore, the role of the government in facilitating and funding research is one of the key factors in increasing publications. According to Van Der Pol (2024), the government plays an important role in technological development as it serves as a vital function as a link between researchers and industry. Government support in terms of facilities and funding has had a positive effect and resulted in higher quality research output. Therefore, the issue of the lack of publications related to POFA will become a challenge for the government, industry and researchers, particularly for the largest palm oil producing countries.

Challenges in Selecting Journals for Publication

The selection of a journal for publishing an article generally reflects the quality of the article's discussion. The Q score can serve as a reference to assess the quality of a journal in comparison with other journals in the relevant field (Asan & Aslan, 2020). According to Li et al. (2026), based on the seven journals with the highest number of publications in 2021 (Scientific Reports, Sustainability, PLoS One, Applied Sciences-Basel, IEEE Access, International Journal of Environmental Research and Public Health, and International Journal of Molecular Sciences), it was found that Q1 journals ranked first with the highest total number of citations, amounting to 12,510,167 times or 64.99% of the total citations. This was followed by Q2 journals (4,553,027 times), Q3 (1,637,546 times) and Q4 (547,596 times). The results of the bibliometric analysis of the top 10 ranked journals show that documents from Q2 sources (12 documents) and Q3 sources (15 documents) tend to have fewer citations. Meanwhile, documents from Q1 sources (79 documents) tend to have a higher number of citations. It is known that journals with a higher Q score have stricter peer review and a stronger editorial board, resulting in more systematic, critical and in-depth discussions. Consequently, journals with a higher Q score are more likely to be recommended, read (if open-access) and cited as references for another research. This presents a particular challenge for researchers to produce higher-quality research articles related to POFA, select the right journals, and establish research collaborations so that the research outcomes are expected to have a greater impact on future research development or be directly applied in the industrial sector.

Opportunities for POFA Utilisation

Bibliometric analysis using "co-occurrence" analysis with the unit of analysis being "all keywords" can demonstrate the current state of research related to POFA utilisation. The results obtained from the analysis show opportunities for the utilisation of POFA waste due to the properties and characteristics possessed by this material. As previously explained, POFA is in the form of fine particles, is porous, and its main components are silica and alumina. In general, the utilisation of waste or biomass from the palm oil industry will certainly be more cost-effective and renewable (Hoerudin et al., 2025). Several previous studies have already utilised or applied POFA in various fields. As shown in *Table 6*, the utilisation of POFA is based on the frequency of occurrence from the keyword analysis conducted.

Research related to the utilisation of POFA as a mixture in concrete, cement, and mortar is the most frequently encountered keyword from the analysis conducted. The use in this field is based on the properties or characteristics of POFA material, which can be classified as a fly ash/pozzolan material in accordance with the requirements of ASTM C618 (ASTM International, 2019). POFA can be categorised under ASTM C618 class F, with its major chemical composition consisting of silica-alumina-iron (Lin et al., 2024). The high percentage of silica oxide is expected to react with $Ca(OH)_2$, producing calcium silicate hydrate (C-S-H) to improve the density and durability of concrete (Amran et al., 2021). POFA material is also a fine particle that is beneficial for increasing the density, flexural strength and material resistance (Hamada et al., 2023b). The fine POFA particles will fill the micro-sized voids in the concrete mixture, thereby enhancing the quality of the concrete microstructure and reducing porosity, resulting in a low permeability value (Hasan et al., 2023). The fineness of POFA particles is estimated to be 2.75 times finer than OPC particles (Salam et al., 2022). With these properties and characteristics, several studies have used POFA as a partial substitute or filler in concrete, cement, and mortar mixtures. Several studies have reported positive effects of POFA addition, such as increased compressive strength (Zaimi et al., 2023), low porosity and water absorption (Shaladi et al., 2022), high density (Siregar et al., 2024), enhanced tensile and flexural strength (Hong et al., 2023), and others. Based on the keyword analysis obtained, it is evident that the research focus is related to the influence of pre-treatment (size, activation, temperature, or washing), modification of mixtures (mixtures with fibre, fly ash, or polymer), and special concrete applications (self-compacting concrete, geopolymer concrete, or ultra-high performance concrete). Based on these findings, several potential research opportunities are apparent, one of which is life cycle assessment (LCA) or green construction using POFA as a substitute for Portland cement. It has been reported that Portland cement production increases by 9% each year and emits around 1.5 billion tonnes of GHG, or about 6% of the total GHG from industry (Amran et al., 2021). Other research opportunities include optimisation and quality improvement with certain mixtures, which are still rarely conducted. Research related to economic analysis, technical standard feasibility testing, as well as industrial scale use and commercialisation are also some possible research avenues for the future.

The utilisation of POFA as a soil stabiliser is one of the most widely conducted research areas at present, aiming to replace lime and cement materials. Lime and cement are commonly used mixtures;

however, they are costly and not environmentally friendly (Khasib et al., 2023). The use of POFA as a soil stabiliser is due to its high silica content, which is beneficial for increasing the strength and durability of soil through its reaction with calcium hydroxide, thereby forming C-S-H (Dwina et al., 2024). Based on the keyword analysis obtained, current research focuses on the application to various types of soil (residual soil, marine clay, peat soil, black cotton soil, clay, tropical clay, tropical laterite soil, and others), pre-treatment and mixture focus (xanthan gum, MgO, lime and others), and characteristic testing (SEM, XRD, EDX and others). From this analysis, several research development opportunities include the relationship between the utilisation of POFA as a soil stabiliser and environmental sustainability, problem-based research in specific regions, optimisation, and feasibility testing for field application.

TABLE 6. MAJOR USES OF PALM OIL FUEL ASH (POFA) BASED ON OCCURRENCE

Rank	Utilisation of POFA based on keywords	Occurrances
1	Concretes	102
2	Cements	66
3	Soil stabilisation	20
4	Adsorbent	19
5	Mortar	19
6	Asphalt	11
7	Ceramic	6
8	Brick	5
9	Membrane	5

The utilisation of POFA as an adsorbent and membrane is one of the areas of research that is currently being increasingly developed. This is clearly illustrated in *Figure 7*, where its use as an adsorbent is indicated by the yellow circle, which shows the publication period in 2024. The use as an adsorbent is based on the dominance of the silica-alumina composition found in POFA, its porous morphology, volume capacity, and high surface area (Senila & Cadar, 2024). The advantages of using POFA waste as an adsorbent include lower production costs, ease of use, and environmental safety (non-toxic) (Rainiyati et al., 2022). POFA adsorbent as a natural zeolite allows for interactions between the adsorbent and adsorbate in the form of physisorption (physical adsorption) and chemisorption (chemical adsorption) (Yue et al., 2022). Therefore, the utilisation of POFA based on previous research has a very broad scope for various contaminants such as heavy metals, colour, inorganics, wastewater, and palm oil. Based on *Figure 7*, the red box shows that several studies on the use of POFA as an adsorbent do not have interconnecting lines with each other. This indicates opportunities for future research that could link the results between studies, either in the form of further development or as review articles. Another research opportunity lies in the potential use of active materials or additives, such as metal ions (Fe, Mg, Cu, Zn and others), surfactants (MES, HDTMA, CTAB and others), or biomass to enhance adsorption capacity and selectivity. To date, there remain broad opportunities in the utilisation of POFA as an adsorbent, for example, its use on contaminants in the form of anions (phosphate,

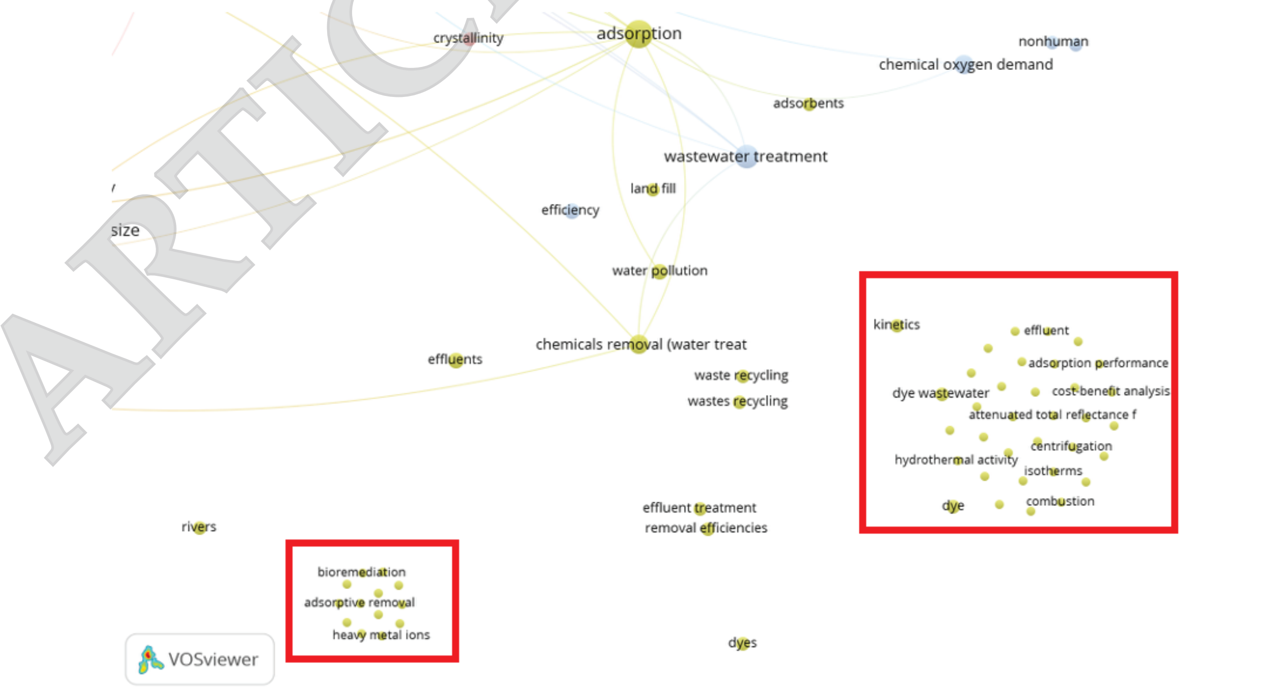

Figure 7. Research the potential of palm oil fuel ash (POFA) for utilisation as an adsorbent.

chloride, fluoride, nitrate and others), discussions related to specific molecular interactions, scale-up of adsorbent use, adsorbent regeneration, and adsorbent optimisation.

Based on *Figure 8*, there is currently recent research related to the utilisation of POFA as a mixture material in asphalt. The utilisation of POFA in asphalt can be achieved through the cold mix asphalt (CMA) process, which saves up to 100% energy and reduces the threat of gas emissions (Usman et al., 2021). The use of POFA as a binder substitute will decrease pavement deterioration and lower life cycle costs (Hin et al., 2024). Research opportunities in the utilisation of POFA as asphalt remain very broad, starting from the formation process (HMA, WMA, CMA, and others), modification or addition of mixtures, further analysis for standardisation, to implementation in the field.

The results of the keyword analysis also show the utilisation of POFA as a mixture material for porcelain and bricks. The use of POFA is based on the presence of quartz crystals, namely the high silica (SiO_2) component in the material (Riascos et al., 2026). The use of silica from POFA will reduce large-scale clay usage and save energy in the brick manufacturing process (Tjaronge & Caronge, 2021). Previous research utilised POFA in the production of fired clay bricks, resulting in lightweight bricks but potentially lowering the density of the mixture due to increased porosity (Kadir & Sarani, 2020). Research conducted by Mora-Ruiz et al. (2026), demonstrated that the manufacture of compressed earth blocks (CEBs) with a mixture of 4%–6% POFA would enhance the compressive and flexural strength of the bricks produced. However, increasing the percentage of POFA to 8%–10% leads to a decrease in brick strength due to the material becoming more sensitive and an increase in moisture content. Although the use of POFA at higher percentages may cause porosity effects, according to Raheem et al. (2025), the presence of POFA also improves the thermal insulation of the material. This improvement will result in better quality bricks like heat insulators, making buildings more energy efficient. Therefore, future research opportunities include discussions on optimising or balancing the values between strength, porosity, and thermal insulation of the bricks produced. The successful use of POFA material will provide opportunities for research related to low-carbon brick technology. Such research can be linked to the impact on CO_2 emissions, as it utilises technology without kilns and cures at low temperatures. Other research opportunities include comparing or mixing POFA with other biomass such as rice husk, sugarcane bagasse, or wheat, which have a high silica composition.

The results of previous research keyword analysis indicate the potential utilisation of POFA as a membrane material. The use of POFA as a membrane material is due to its high metal oxide content, high porosity, good particle distribution, and large surface area (Shenvi et al., 2016). Research conducted by Abuabdou et al. (2021), showed that the addition of POFA to PVDF membranes resulted in increased rejection and antifouling. Based on previous studies, the use of POFA as a membrane material is still very limited, as shown in *Figure 9*. Therefore, there are still many opportunities for further research, such as variations in membrane

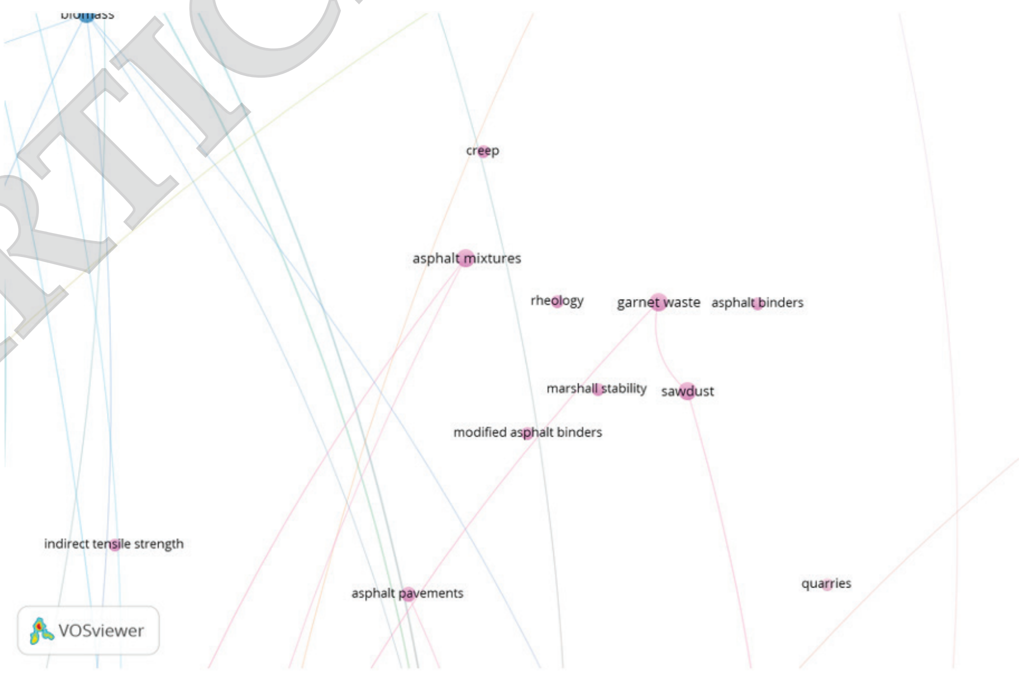

Figure 8. Research the conditions of palm oil fuel ash (POFA) with utilisation as asphalt.

types, polymers or mixture materials used, application to specific contaminants (textile, rubber, wastewater), or even review articles related to the utilisation of POFA as a membrane, which have not yet been found.

CONCLUSION

Trend analysis conducted on POFA publications from 1995 to 2025 shows a tendency for an increase in publications over the past 10 years. POFA publications from 1995 to 2009 were more focused on issues related to agricultural, chemical, and medical science research. The number of publications related to POFA began to rise significantly in 2014 due to growing concerns about environmental problems resulting from a significant increase in production. As a result, several countries or regions began to regulate the palm oil industry with policies or regulations such as RSPO, MSPO, ISPO, ESPO certifications, and other green energy policies. By 2025, there were as many as 32 publication documents indicating that POFA issues had started to become a main focus of discussion in the sustainability of the palm oil industry.

The results of bibliometric analysis of journals used in POFA article publications show that the majority of journals have a main focus in the fields of "engineering", "material science", and "environmental science". The analysis also shows that there are several documents published in Q2 and Q3, but with a low number of citations and IF scores. This is certainly a challenge for researchers to produce higher quality research articles, select the appropriate journals, and establish research collaborations so that the research outcomes are expected to have a greater impact on the development of future research or be directly applied to the industrial sector.

Bibliometric analysis using the unit of analysis "country" shows that Malaysia is the largest contributor to research related to POFA, accounting for 77.941% of the total documents. This result is also consistent with the analysis of institutions and authors, which are also dominated by Malaysia. From these data, it must be acknowledged that the majority of discussions and issues related to POFA are based on the conditions or circumstances occurring in Malaysia. This is because the focus of palm oil industry development in Malaysia is no longer on land expansion but on improving quality, as per the targets set in the MSPO certification. On

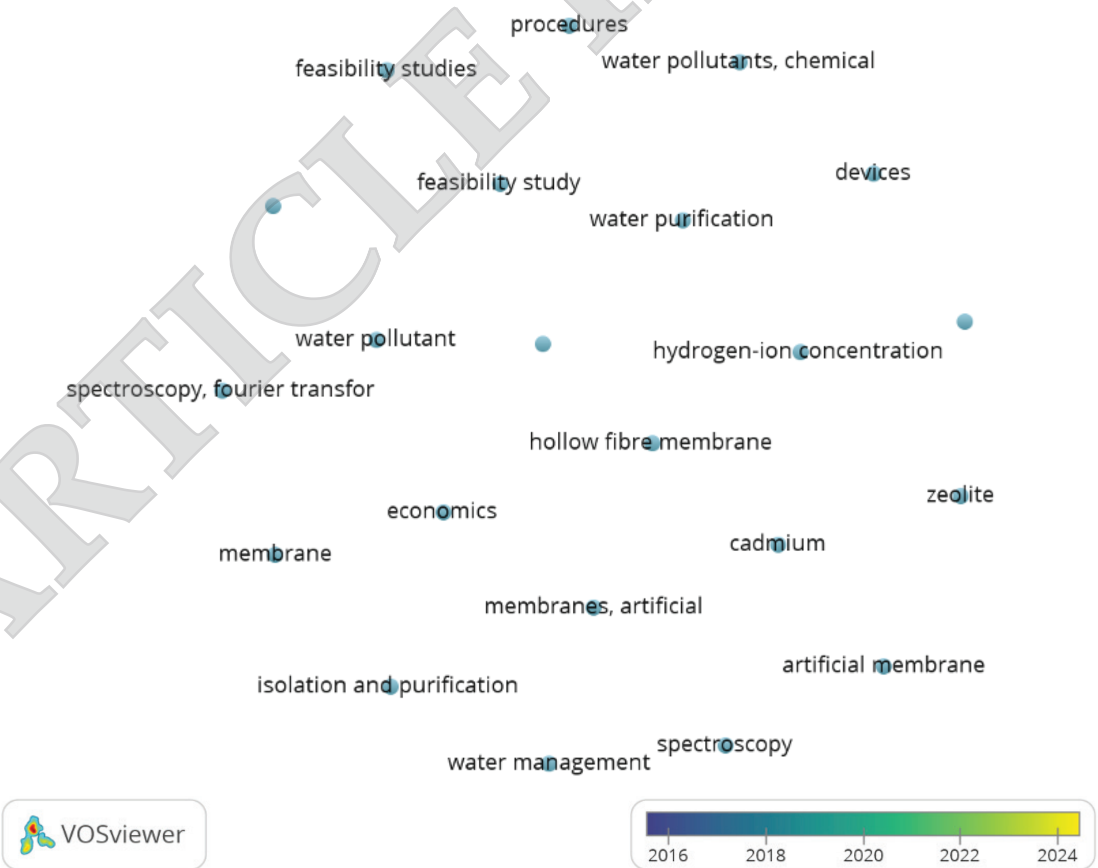

Figure 9. Research the conditions of palm oil fuel ash (POFA) with utilisation as a membrane.

the other hand, there are challenges for several other major palm oil producing countries such as Indonesia, Thailand, and Colombia, which still have limited publications related to POFA. A 3% increase in production over the past 10 years, improper handling, and the threats posed by POFA to the environment will increase the urgency for producing countries to create innovations, such as the utilisation of POFA.

Furthermore, through keyword analysis, the focus of existing research can be seen, which is dominated by the main keywords, namely "palm oil fuel ash", "pofa", and "palm oil fuel ash (pofa)". The majority of keywords related to the utilisation of POFA are associated with construction materials, such as "portland cement", "mortar", "cement", "geopolymer", "binder", and "concrete". Further analysis of keywords from previous studies reveals the current status and potential for utilising POFA across various fields. Research on the use of POFA as an additive in concrete, cement, and mortar currently focuses on the effects of pre-treatment (size, activation, temperature, or washing), mixture modification (blending with fibres, fly ash, or polymers), and specialised concrete applications (self-compacting concrete, geopolymer concrete, or ultra-high performance concrete). Future research opportunities may include discussions on life cycle assessment (LCA) linked to carbon emissions, mixture optimisation, economic analysis, up-scaling, and commercial viability. Research opportunities regarding the use of POFA as a soil stabiliser relate to environmental sustainability, problem-based research in specific regions, and optimisation and feasibility testing for field application. In its use as an adsorbent, research on POFA could take the form of review articles linking existing studies, the addition of active materials, the adsorption of anionic contaminants, specific discussions regarding molecular interactions, the scale-up of adsorbent use, adsorbent regeneration, and adsorbent optimisation. Meanwhile, the use of POFA in asphalt, bricks, and membranes still offers extensive opportunities for further research. Therefore, the results of the bibliometric analysis of the keywords indicate that there remains a wide scope for research and discussion regarding POFA research in the future.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to the Department of Chemical Engineering at Diponegoro University for providing the facilities for this research. Thanks are also extended to the team members and lecturers who have assisted, taught and guided the authors in completing this research.

REFERENCES

Abdulhaleem, K. N., Hamada, H. M., Majdi, A., & Yousif, S. T. (2025). Influence of palm oil fuel ash as agricultural waste on the environment and strength of geopolymer concrete. *Research on Engineering Structures and Materials*, *11*(2), 647–662. https://doi.org/10.17515/resm2024.306ma0602rv

Abuabdou, S. M. A., Bashir, M. J. K., Aun, N. C., Sethupathi, S., & Yong, W. L. (2021). Development of a novel polyvinylidene fluoride membrane integrated with palm oil fuel ash for stabilized landfill leachate treatment. *Journal of Cleaner Production*, *311*, 127677. https://doi.org/10.1016/j.jclepro.2021.127677

Adwiyah, R., Syaukat, Y., Indrawan, D., & Mulyati, H. (2023). Examining sustainable supply chain management (SSCM) performance in the palm oil industry with the triple bottom line approach. *Sustainability*, *15*(18), 13362. https://doi.org/10.3390/su151813362

Aisyah, S., Imelda, D., Busrizal, & Hakim, M. A. (2024). The utilization of a mixture of palm oil and shellfish industrial waste in producing paving block. *Jurnal Keteknikan Pertanian*, *12*(3), 352–361. https://doi.org/10.19028/jtep.012.3.352-361

Amran, M., Murali, G., Fediuk, R., Vatin, N., Vasilev, Y., & Abdelgader, H. (2021). Palm oil fuel ash-based eco-efficient concrete: A critical review of the short-term properties. *Materials*, *14*(2), 332. https://doi.org/10.3390/ma14020332

Anam, K., Fauzi, A., Hendrarini, H., & Maroeto. (2025). Export and performance analysis of Indonesian palm oil companies facing sustainability policies in the European markets using PLS-SEM. *Jurnal Penelitian Pendidikan IPA*, *11*(8), 1206–1216. https://doi.org/10.29303/jppipa.v11i8.12463

Anggoro, D. D., Muzadi, M. H., Le Monde, B. U., Sudiyarmanto, S., & Rustyawan, W. (2025). Bibliometric analysis of boehmite catalyst research. *E3S Web of Conferences*, *655*, *01008*. https://doi.org/10.1051/e3sconf/202565501008

Asan, A., & Aslan, A. (2020). Quartile scores of scientific journals: Meaning, importance and usage. *Acta Medica Alanya*, *4*(1), 102–108. https://doi.org/10.30565/medalanya.653661

Astari, A. J., Lovett, J. C., & Wasesa, M. (2025). Sustainable pathways in Indonesia's palm oil industry through historical institutionalism.

World Development Sustainability, *6*, 100200. https://doi.org/10.1016/j.wds.2024.100200

ASTM International. (2019). *ASTM C618-19: Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete*. ASTM. https://doi.org/10.1520/C0618-19

Awal, A. S. M. A., & Hussin, M. W. (1997). The effectiveness of palm oil fuel ash in preventing expansion due to alkali-silica reaction. *Cement and Concrete Composites*, *19*(4), 367–372. https://doi.org/10.1016/S0958-9465(97)00034-6

Awoh, E. T., Kiplagat, J., Kimutai, S. K., & Mecha, A. C. (2023). Current trends in palm oil waste management: A comparative review of Cameroon and Malaysia. *Heliyon*, *9*(11), e21410. https://doi.org/10.1016/j.heliyon.2023.e21410

Aziz, I. F. A. B., Che Man, H., Demirci, A., Hamzah, M. H., Omar, R., Jamali, N. S., Katibi, K. K., & Mohammed, A. (2025). Lignocellulosic biomass-derived biogas: A review on sustainable energy in Malaysia. *Journal of Oil Palm Research*, *37*(1), 16–43. https://doi.org/10.21894/jopr.2024.0021

Choiruzzad, S. A. B., Tyson, A., & Varkkey, H. (2021). The ambiguities of Indonesian sustainable palm oil certification: Internal incoherence, governance rescaling and state transformation. *Asia Europe Journal*, *19*(2), 189–208. https://doi.org/10.1007/s10308-020-00593-0

Corrin, L., Thompson, K., Hwang, G.-J., & Lodge, J. M. (2022). The importance of choosing the right keywords for educational technology publications. *Australasian Journal of Educational Technology*, *38*(2), 1-8. https://doi.org/10.14742/ajet.8087

De Hoop, E., & Van Der Vleuten, E. (2022). Sustainability knowledge politics: Southeast Asia, Europe and the transregional history of palm oil sustainability research. *Global Environment*, *15*(2), 209–245. https://doi.org/10.3197/ge.2022.150202

Demirboga, R., & Farhan, K. Z. (2022). Palm oil fuel ash (POFA). In R. Siddique & R. Belarbi (Eds.), *Sustainable concrete made with ashes and dust from different sources: Materials, properties and applications* (pp. 294–330). Woodhead Publishing. https://doi.org/10.1016/B978-0-12-824050-2.00006-1

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research*, *133*, 285–296. https://doi.org/10.1016/j.jbusres.2021.04.070

Dwina, D. O., Abiyoga, N. P., & Nurdin, A. (2024). Palm oil fuel ash fineness in modifying CBR characteristics of peat soil. *Bentang: Jurnal Teoritis dan Terapan Bidang Rekayasa Sipil*, *12*(2), 202–210. https://doi.org/10.33558/bentang.v12i2.9598

European Palm Oil Alliance. (2019). *Choosing sustainable palm oil*. https://palmoilalliance.eu/epoa-magazine-december-2019/

Etzkowitz, H., & Leydesdorff, L. (1995). The triple helix – University-industry-government relations: A laboratory for knowledge based economic development. *EASST Review, 14*(1), 14–19.

European Union. (2009). Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. *Official Journal of the European Union*, *52*(L 140), 16–62. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32009L0028

Ezreig, A. M. A., Ismail, M. A. M., & Ehwailat, K. I. A. (2023). Geotechnical performance of tropical laterite soil using palm oil fuel ash and activator magnesium oxide stabilizer. *Physics and Chemistry of the Earth A/B/C*, *129*, *103293*. https://doi.org/10.1016/j.pce.2022.103293

Foo, K. Y., & Hameed, B. H. (2009). Value-added utilization of oil palm ash: A superior recycling of the industrial agricultural waste. *Journal of Hazardous Materials*, *172*(2–3), 523–531. https://doi.org/10.1016/j.jhazmat.2009.07.091

Gasper, D., Shah, A., & Tankha, S. (2019). The framing of sustainable consumption and production in SDG 12. *Global Policy*, *10*(S1), 83–95. https://doi.org/10.1111/1758-5899.12592

Gopal, K. P. S., & Chamberlin, K. S. (2023). Experimental study on black cotton soil treated with xanthan gum and palm oil fuel ash. *E3S Web of Conferences*, *391*, 01017. https://doi.org/10.1051/e3sconf/202339101017

Hamada, H., Abed, F., Alattar, A., Yahaya, F., Tayeh, B., & Aisheh, Y. I. A. (2023a). Influence of palm oil fuel ash on the high strength and ultra-high performance concrete: A comprehensive review.

Engineering Science and Technology, an International Journal, *45*, 101492. https://doi.org/10.1016/j.jestch.2023.101492

Hamada, H. M., Al-Attar, A., Shi, J., Yahaya, F., Al Jawahery, M. S., & Yousif, S. T. (2023b). Optimization of sustainable concrete characteristics incorporating palm oil clinker and nano-palm oil fuel ash using response surface methodology. *Powder Technology*, *413*, 118054. https://doi.org/10.1016/j.powtec.2022.118054

Hamzah, M. A. A. M., Yusof, N., Zaini, M. A. A., Zakaria, Z. A., Jaafar, J., & Misdan, N. (2025). Advancing heavy metal removal from industrial wastewater using oil palm waste-based adsorbent: Toward efficient adsorption and commercialization. *Current Pollution Reports*, *11*, 52. https://doi.org/10.1007/s40726-025-00381-7

Hanifa, N. H. E., Ismail, M., & Ideris, A. (2022). Utilization of palm oil fuel ash (POFA) as catalyst support for methane decomposition. *Materials Today: Proceedings*, *57*, 1136–1141. https://doi.org/10.1016/j.matpr.2021.10.007

Hansen, S. B., Padfield, R., Syayuti, K., Evers, S., Zakariah, Z., & Mastura, S. (2015). Trends in global palm oil sustainability research. *Journal of Cleaner Production*, *100*, 140–149. https://doi.org/10.1016/j.jclepro.2015.03.051

Hasan, N. M. S., Sobuz, M. H. R., Shaurdho, N. M. N., Meraz, M. M., Datta, S. D., Aditto, F. S., Kabbo, M. K. I., & Miah, M. J. (2023). Eco-friendly concrete incorporating palm oil fuel ash: Fresh and mechanical properties with machine learning prediction, and sustainability assessment. *Heliyon*, *9*(11), e22296. https://doi.org/10.1016/j.heliyon.2023.e22296

Hin, M. S. W. N., Ramadhansyah, P. J., & Masri, K. A. (2024). Palm oil fuel ash, garnet waste and sawdust as modified asphalt mixture: A critical review. *IOP Conference Series: Earth and Environmental Science*, *1296*(1), 012004. https://doi.org/10.1088/1755-1315/1296/1/012004

Hoerudin, H., Hidayat, T., Yulianto, A., Agustina, S., Fajriyan, F., Karnadi, K., Majid, A., Suhendra, A., Hartanto, E. S., & Kamil, A. (2025). Biogenic silica from oil palm biomass: A review on the potential, extraction methods and properties. *Journal of Oil Palm Research*. https://doi.org/10.21894/jopr.2025.0036

Hong, W. C., Mohammed, B. S., Abdulkadir, I., & Liew, M. S. (2023). Modeling and optimizing the effect of palm oil fuel ash on the properties of engineered cementitious composite. *Buildings*, *13*(3), 628. https://doi.org/10.3390/buildings13030628

Hossain, M. S., Panov, V., Choi, S., Kim, J. B., & Yun, K. K. (2024). Durability performance of cement mortar incorporating water-repellent admixtures. *Construction and Building Materials*, *440*, 137262. https://doi.org/10.1016/j.conbuildmat.2024.137262

Huseien, G. F., Asaad, M. A., Abadel, A. A., Ghoshal, S. K., Hamzah, H. K., Benjeddou, O., & Mirza, J. (2022). Drying shrinkage, sulphuric acid and sulphate resistance of high-volume palm oil fuel ash-included alkali-activated mortars. *Sustainability*, *14*(1), 498. https://doi.org/10.3390/su14010498

Jamil, M., & Asrol, M. (2024). Palm oil sustainability: Current and further potential research to adopt sustainable development goals 2030. *IOP Conference Series: Earth and Environmental Science*, *1324*, 012077. https://doi.org/10.1088/1755-1315/1324/1/012077

Jamo, H. U., Umar, I. D., Abdu, S., Tambalo, Z. A., Abdulkarim, S., Salisu, I. T., Liman, A. M., Abdullahi, M. B., & Izzudden, M. (2022). Improvement of porcelain physical properties through the substitution of quartz element with rice husk ash and palm oil fuel ash. *Science World Journal*, *17*(1), 38–44.

Isa, M. N., & Awang, H. (2023). Characteristics of palm oil fuel ash geopolymer mortar activated with wood ash lye cured at ambient temperature. *Journal of Building Engineering*, *66*, 105851. https://doi.org/10.1016/j.jobe.2023.105851

Ismail, M. H., Megat Johari, M. A., Ariffin, K. S., Jaya, R. P., Wan Ibrahim, M. H., & Yugashini, Y. (2022). Performance of high strength concrete containing palm oil fuel ash and metakaolin as cement replacement material. *Advances in Civil Engineering*, *2022*, 6454789. https://doi.org/10.1155/2022/6454789

Judijanto, L. (2026). The dynamics palm oil regulation and policy in Indonesia: A literature review on the relationship between local regulations, environmental governance, and sustainability efforts from a sustainable development perspective. *International Journal of Financial Economics (IJEFE)*, *2*(8), 1483–1494.

Kadir, A. A., & Sarani, N. A. (2020). Utilization of palm oil fuel ash in brick manufacturing for lightweight fired clay brick production. *International Journal of Sustainable Construction Engineering and Technology*, *11*(1), 136–150.

Kahar, P., Rachmadona, N., Pangestu, R., Palar, R., Triyono Nugroho Adi, D., Betha Juanssilfero, A., Yopi, Manurung, I., Hama, S., & Ogino, C. (2022). An integrated biorefinery strategy for the utilization of palm-oil wastes. *Bioresource Technology*, *344*, 126266. https://doi.org/10.1016/j.biortech.2021.126266

Kartikowati, R. S. (2024). Bibliometric mapping: Research development on the topic of quality management on google schoolar using VOSviewer. *Jurnal Ilmiah Peuradeun*, *12*(3), 1467–1484. https://doi.org/10.26811/peuradeun.v12i3.1125

Khasib, I. A., Nik Daud, N. N., & Izadifar, M. (2023). Consolidation behaviour of palm-oil-fuel-ash-based geopolymer treated soil. *Geotechnical Research*, *10*(3), 138–152. https://doi.org/10.1680/jgere.23.00013

Khatrinatasa, S. (2025). Impact of palm oil waste management activities in Arongan Village, Kuala Pesisir District, Nagan Raya Regency. *Journal of Political and Governance Studies, 1*(1), 49–58. https://doi.org/10.64670/jpgs.v1i1.8

Kirby, A. (2023). Exploratory bibliometrics: Using VOSviewer as a preliminary research tool. *Publications*, *11*(1), 10. https://doi.org/10.3390/publications110100100

Krishnan, T., Mohd Suradi, N. R., & Shahabuddin, F. A. (2025). Paradigm shift to quadruple helix model of innovation in Malaysia. *Journal of Quality Measurement and Analysis*, *21*(1), 105–112. https://doi.org/10.17576/jqma.2101.2025.06

Li, J., Wu, D., & Chen, X. (2026). The influence of multidisciplinary mega-journals on the journal impact factor: Discipline, country/region, category, JIF quartile, and journal. *Data and Information Management*, *10*(1), 100112. https://doi.org/10.1016/j.dim.2025.100112

Liew, Y. X., Doh, S. I., & Chin, S. C. (2024). A comprehensive review on the impact of micro and nano palm oil fuel ash in cementitious material. *Materials Today: Proceedings*, *107*, 216–223. https://doi.org/10.1016/j.matpr.2023.10.037

Lim, J. Q., Mohd Zaki, R. S. R., Miskan, S. N., Ainirazali, N., & Jaafar, N. F. (2022). Optimization of Pb(II) removal using magnetic gamma-Fe_2O_3 /KCC-1 synthesized from palm oil fuel ash. *Journal of Chemical Engineering and Industrial Biotechnology*, *8*(1), 18-26. https://doi.org/10.15282/jceib.v8i1.7774

Lin, J., Tan, T. H., Yeo, J. S., Goh, Y., Ling, T. C., & Mo, K. H. (2024). Optimization of the manufacturing process and properties of alkali-activated palm oil fuel ash-based cold-bonded aggregates. *Journal of Cleaner Production*, *437*, 18–26.

Matsimbe, J., Dinka, M., Olukanni, D., & Musonda, I. (2022). A bibliometric analysis of research trends in geopolymer. *Materials*, *15*(19), 6979. https://doi.org/10.3390/ma15196979

Michida, E. (2023). *Effectiveness of self-regulating sustainability standards for the palm oil industry* (ERIA Discussion Paper No. 476). Economic Research Institute for ASEAN and East Asia. https://www.eria.org/research/effectiveness-of-self-regulating-sustainability-standards-for-the-palm-oil-industry

Mora-Ruiz, V., Mejía-Parada, C., & Tavera, C. (2026). Mechanical and microstructural performance of compressed earth blocks stabilized with palm oil fuel ash: Experimental study, systematic review and meta-analysis. *Journal of Building Engineering*, *122*, 115804. https://doi.org/10.1016/j.jobe.2026.115804

Murphy, D. J., Goggin, K., & Paterson, R. R. M. (2021). Oil palm in the 2020s and beyond: Challenges and solutions. *CABI Agriculture and Bioscience*, *2*(1), 39. https://doi.org/10.1186/s43170-021-00058-3

Mustafa, I., Fathurrahmi, Suriarah, Farida, M., & Ahmad, K. (2022). Palm shell-derived activated carbon adsorbent is better than of coconut shell: Comparative studies of COD adsorption from palm oil mill effluent. *RASAYAN Journal of Chemistry*, *15*(2), 738–744. https://doi.org/10.31788/RJC.2022.1526804

Mustapa, F. H. (2025). Malaysian palm oil price prediction using ARIMA-ARCH model. *Oil Palm Industry Economic Journal*, *25*(1), 21–30. https://doi.org/10.21894/opiej.2025.01

Naidu, L., & Moorthy, R. (2021). A review of key sustainability issues in Malaysian palm oil industry. *Sustainability*, *13*(19), 10839. https://doi.org/10.3390/su131910839

Nasution, D. W., Hastuty, I. P., Roesyanto, R., & Anisa, S. (2023). Stabilisasi tanah lempung menggunakan palm oil fuel ash (POFA) dan

20% kapur dolomit ($CaMg(CO_3)_2$) ditinjau dari CBR dan kuat tekan bebas [Stabilization of clay soil using palm oil fuel ash (POFA) and 20% dolomite lime ($CaMg(CO_3)_2$) based on CBR and unconfined compressive strength]. *Blend Sains Jurnal Teknik*, *2*(3), 218–227. https://doi.org/10.56211/blendsains.v2i3.397

Ngan, S. L., Er, A. C., Yatim, P., How, B. S., Lim, C. H., Ng, W. P. Q., Chan, Y. H., & Lam, H. L. (2022). Social sustainability of palm oil industry: A review. *Frontiers in Sustainability*, *3*, *855551*. https://doi.org/10.3389/frsus.2022.855551

Onsongo, S. K., Olukuru, J., Munyao, O. M., & Mwabonje, O. (2025). The role of agricultural ashes (rice husk ash, coffee husk ash, sugarcane bagasse ash, palm oil fuel ash) in cement production for sustainable development in Africa. *Discover Sustainability*, *6*(1), 62. https://doi.org/10.1007/s43621-025-00841-6

Oyehan, T. A., Salami, B. A., Badmus, S. O., & Saleh, T. A. (2022). Technological trends in activation and modification of palm oil fuel ash for advanced water and wastewater treatment – A review. *Sustainable Chemistry and Pharmacy*, *29*, 100754. https://doi.org/10.1016/j.scp.2022.100754

Padmalia, M. (2023). Firm resilience research development: A bibliometric analysis with VOSviewer. *International Journal of Economics, Business and Accounting Research (IJEBAR)*, *7*(1), 274–286.

Patah, D., Dasar, A., & Nurdin, A. (2025). Sustainable concrete using seawater, sea-sand, and ultrafine palm oil fuel ash: Mechanical properties and durability. *Case Studies in Construction Materials*, *22*, e04129. https://doi.org/10.1016/j.cscm.2024.e04129

Pelita, E., Youfa, R., Desniorita, D., Sahaq, A. B., Miftahurrahmah, M., Permadani, R. L., & Jerry, J. (2023). Effect of dolomite addition on the performance of palm oil mill fly ash for methylene blue adsorption. *Indonesian Journal of Chemical Analysis (IJCA)*, *6*(1), 63–74. https://doi.org/10.20885/ijca.vol6.iss1.art7

Pye, O. (2019). Commodifying sustainability: Development, nature and politics in the palm oil industry. *World Development*, *121*, 218–228. https://doi.org/10.1016/j.worlddev.2018.02.014

Raheem, H. O., Abas, N. F., Shanmugan, S., Ban, C. C., & Tersoo, K. E. (2025). Enhancing the thermal efficiency of unfired laterite bricks stabilized with seashell powder and palm oil fuel ash for sustainable construction. *Construction and Building Materials*, *496*, 143840. https://doi.org/10.1016/j.conbuildmat.2025.143840

Rahman, M. H., Kong, S. Y., Lam, B. Y. B., Murali, G., Wong, L. S., & Paul, S. C. (2024). Effects of palm oil fuel ash and crumb rubber on mechanical and thermal properties of sustainable engineered cementitious composites. *Journal of Building Engineering*, *97*, 110795. https://doi.org/10.1016/j.jobe.2024.110795

Rainiyati, R., Riduan, A., Heraningsih, S. F., & Mukhtasida, B. A. (2022). Mercury removal from gold mining wastewater using palm oil fuel ash (POFA). *Journal of Degraded and Mining Lands Management*, *9*(3), 3525–3531. https://doi.org/10.15243/jdmlm.2022.093.3525

Raynaud, M., Goutaudier, V., Louis, K., Al-Awadhi, S., Dubourg, Q., Truchot, A., Brousse, R., Saleh, N., Giarraputo, A., Debiais, C., Demir, Z., Certain, A., Tacafred, F., Cortes-Garcia, E., Yanes, S., Dagobert, J., Naser, S., Robin, B., Bailly, É., … Loupy, A. (2021). Impact of the COVID-19 pandemic on publication dynamics and non-COVID-19 research production. *BMC Medical Research Methodology*, *21*(1), 255. https://doi.org/10.1186/s12874-021-01404-9

Riascos, M., Aponte, D., Barra, M., & Rincon, O. (2026). Use of binder based on palm oil fuel ash for stabilization of tropical clay soils. *Transportation Geotechnics*, *56*, 101752. https://doi.org/10.1016/j.trgeo.2025.101752

Rifai, N., Syaukat, Y., Siregar, H., & Sa'id, E. G. (2014). The development and prospect of Indonesian palm oil industry and its derivative products. *IOSR Journal of Economics and Finance*, *4*(5), 27–39. https://doi.org/10.9790/5933-0452739

Ritchie, H. (2021). *Palm oil*. Our World in Data. https://ourworldindata.org/palm-oil

Rosyidi, S. A. P., Idiajir, B., Akhir, N. M., Rahmad, S., Lestari, N. P., Widoanindyawati, V., Al-Sabaeei, A. M., Milad, A., Mashaan, N. S., & Yusoff, N. I. M. (2022). Physical, chemical and thermal properties of palm oil boiler ash/rediset-modified asphalt binder. *Sustainability*, *14*(5), 3016. https://doi.org/10.3390/su14053016

Roundtable on Sustainable Palm Oil. (2024). *Prinsip dan kriteria RSPO 2024 untuk budi daya sawit berkelanjutan serta produksi minyak sawit dan produk sawit berkelanjutan* [RSPO 2024 principles and criteria for sustainable cultivation of oil palms and production of sustainable palm oil and oil palm products]. https://rspo.org/wp-content/uploads/IND-Version-4-0-Updated-PC-2024_19092025.pdf

Salam, M. A., Safiuddin, M., & Jumaat, M. Z. B. (2022). Mechanical properties and microstructure of self- consolidating high-strength concrete including palm oil fuel ash. *ACI Materials Journal*, *119*(1), 233–249. https://doi.org/10.14359/51732982

Saputra, W., Ichsan, M., Permatasari, A., & Syakira, T. (2021). Biodiesel policy's risks against economy and environment in Indonesia: A stakeholder's perspectives. SPOS Indonesia. https://sposindonesia.org/wp-content/uploads/2021/12/Working-Paper_SPOSI-KEHATI-Eng.pdf

Sata, V., Jaturapitakkul, C., & Kiattikomol, K. (2004). Utilization of palm oil fuel ash in high-strength concrete. *Journal of Materials in Civil Engineering*, *16*(6), 623–628. https://doi.org/10.1061/(asce)0899-1561(2004)16:6(623)

Segovia-Hernández, J. G., Hernández, S., Cossío-Vargas, E., & Sánchez-Ramírez, E. (2023). Challenges and opportunities in process intensification to achieve the UN's 2030 agenda: Goals 6, 7, 9, 12 and 13. *Chemical Engineering and Processing – Process Intensification*, *192*, 109507. https://doi.org/10.1016/j.cep.2023.109507

Senila, M., & Cadar, O. (2024). Modification of natural zeolites and their applications for heavy metal removal from polluted environments: Challenges, recent advances, and perspectives. *Heliyon*, *10*(3), e25303. https://doi.org/10.1016/j.heliyon.2024.e25303

Setianingrum, N., Fitria, N., Omega, R. K., & Chofsah, Z. A. (2024). Sinergi triple helix dalam upaya meningkatkan kualitas sumber daya manusia di Indonesia [Triple helix synergy in efforts to improve the quality of human resources in Indonesia]. *Gudang Jurnal Multidisiplin Ilmu*, *2*(10), 77–82. https://doi.org/10.59435/gjmi.v2i10.958

Shah, J. N., Pradhan, N. M. S., Shrestha, A., & Deo, G. P. (2024). Impact of impact factor, IF: Pros and cons in research, writing, and publication. *Journal of Chitwan Medical College (JCMC)*, *14*(3), 1–7. https://doi.org/10.54530/jcmc.1586

Shahidin, F. S. M., Jalaludin, J., Junaidi, E. S., & Tualeka, A. R. (2021). Associations of exposure to PM10 and PM2.5 withy respiratory health symptoms and lung function status among children living near palm oil activity in Semenyih, Selangor. *Journal of Sustainability Science and Management*, *16*(6), 165–179. https://doi.org/10.46754/jssm.2021.08.015

Shaladi, R. J., Johari, M. A. M., Ahmad, Z. A., & Mijarsh, M. J. A. (2022). The influence of palm oil fuel ash heat treatment on the strength activity, porosity, and water absorption of cement mortar. *Environmental Science and Pollution Research*, *29*(48), 72493–72514. https://doi.org/10.1007/s11356-022-20710-3

Shenvi, S. S., Isloor, A. M., Ahmad, A. L., Garudachari, B., & Ismail, A. F. (2016). Influence of palm oil fuel ash, an agro-industry waste on the ultrafiltration performance of cellulose acetate butyrate membrane. *Desalination and Water Treatment*, *57*(55), 26414–26426. https://doi.org/10.1080/19443994.2016.1171169

Siagian, U. W. R., Wenten, I. G., & Khoiruddin, K. (2024). Circular economy approaches in the palm oil industry: Enhancing profitability through waste reduction and product diversification. *Journal of Engineering and Technological Sciences*, *56*(1), 25–49. https://doi.org/10.5614/j.eng.technol.sci.2023.56.1.3

Siregar, S. M., Humaidi, S., Bukit, N., & Frida, E. (2024). Palm oil fuel ash and fly ash for a partial replacement of cement in high-quality, environmentally friendly mortar as a solution to industrial waste. *Science and Technology Indonesia*, *9*(1), 59–68.https://doi.org/10.26554/sti.2024.9.1.59-68

Sitohang, C., Kuncaka, A., & Suratman, A. (2024). Synthesis of mesoporous silica from palm oil boiler ash (MS-POBA) with addition of methyl ester sulfonate as a template for free fatty acid adsorption from crude palm oil (CPO). *Indonesian Journal of Chemistry*, *24*(3), 729–741. https://doi.org/10.22146/ijc.87703

Sufian, A. N. B. M., Rahman, M. R., Said, K. A. B. M., & Bakri, M. K. (2025). A critical review of various types of palm oil fuel ash (POFA) utilization in enhancing concrete and mortar properties. *Journal of Building Pathology and Rehabilitation*, *10*(2), 124. https://doi.org/10.1007/s41024-025-00622-8

Sumadi, S. R., & Hussin, M. W. (1995). Palm oil fuel ash (POFA) as a future partial cement replacement material in housing construction. *Journal of Ferrocement*, *25*(1), 25–34.

Supriatna, J., Setiawati, M. R., Sudirja, R., Suherman, C., & Bonneau, X. (2022). Composting for a more sustainable palm oil waste management: A systematic literature review. *The Scientific World Journal*, *2022*(1), 5073059. https://doi.org/10.1155/2022/5073059

Sylvia, N., Rinaldi, W., Muslim, A., Husin, H., & Yunardi. (2022). Challenges and possibilities of implementing sustainable palm oil industry in Indonesia. *IOP Conference Series: Earth and Environmental Science*, *969*(1), 012011. https://doi.org/10.1088/1755-1315/969/1/012011

Tahamtan, I., Safipour Afshar, A., & Ahamdzadeh, K. (2016). Factors affecting number of citations: A comprehensive review of the literature. *Scientometrics*, *107*(3), 1195–1225. https://doi.org/10.1007/s11192-016-1889-2

Tai, Z. S., Othman, M. H. D., Mustafa, A., Mohamed Dzahir, M. I. H., Hubadillah, S. K., Koo, K. N., Azalia, M. A., Alias, N. H., Ooi, B. S., Kurniawan, T. A., & Ismail, A. F. (2021). Design and characterization of ceramic hollow fiber membrane derived from waste ash using phase inversion-based extrusion/sintering technique for water filtration. *Journal of Asian Ceramic Societies*, *9*(1), 318–335. https://doi.org/10.1080/21870764.2020.1868080

Tjaronge, M. W., & Caronge, M. A. (2021). Physico-mechanical and thermal performances of eco-friendly fired clay bricks incorporating palm oil fuel ash. *Materialia*, *17*, 101130. https://doi.org/10.1016/j.mtla.2021.101130

Uba, A. R., Jamo, H. U., Ismail, U. I., Musa, F. U., & Gwadabe, S. H. (2024). The determination of heterogeneous catalytic performance of palm oil fuel ash (POFA) in the production of biodiesel via transesterification of jatropha oil. *Science World Journal*, *19*(1), 13–16. https://doi.org/10.4314/swj.v19i1.3

Umer, M., Zada, N. S., Awoyera, P. O., Khan, M. B., Ahmed, W., & Fadugba, O. G. (2026). Synergistic effects and optimization of palm oil fuel ash and jute fiber in sustainable concrete. *Scientific Reports*, *16*, 259. https://doi.org/10.1038/s41598-025-27579-5

United Nations Development Programme. (1997). *Governance for sustainable human development. A UNDP policy document.* https://digitallibrary.un.org/record/492551

United Nations. (2015). *Transforming our world: The 2030 agenda for sustainable development*. https://sdgs.un.org/publications/transforming-our-world-2030-agenda-sustainable-development-17981

U.S. Department of Agriculture. (2025). *Production - Palm oil*. https://www.fas.usda.gov/data/production/4243000

Usman, K. R., Hainin, M. R., Mohd Satar, M. K. I., Mohd Warid, M. N., Kamarudin, S. N. N., & Abdulrahman, S. (2021). Palm oil fuel ash application in cold mix dense-graded bituminous mixture. *Construction and Building Materials*, *287*, 123033. https://doi.org/10.1016/j.conbuildmat.2021.123033

Van Der Pol, J. (2024). The impact of funding on the 5G innovation ecosystem. *Scientometrics*, *129*(4), 2037–2056. https://doi.org/10.1007/s11192-024-04954-z

Van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, *84*(2), 523–538. https://doi.org/10.1007/s11192-009-0146-3

Xu, T., Du, M., Yan, Y., & Singh, S. (2025). Wood-derived biochar for sustainable water remediation: Insights into modification techniques, adsorption performance, techno-economic aspects, and future outlook. *Journal of Molecular Structure*, *1346*, 143141. https://doi.org/10.1016/j.molstruc.2025.143141

Yadollahi, S., Ardeshir, A., & Sharifi Khobdeh, M. (2025). Harvesting a legacy: The evolution of palm oil's global footprint – A strategic journey of economic growth and sustainability. *Forestry Economics Review*, *8*(1), 2–31. https://doi.org/10.1108/fer-04-2025-0006

Yang, X., & Li, T. (2024). Does the COVID-19 pandemic affect excellence in academic research? A study of science and engineering faculty members in China. *Higher Education Policy*, *37*(3), 532–548. https://doi.org/10.1057/s41307-023-00313-4

Yaro, N. S. A., Sutanto, M. H., Habib, N. Z., Napiah, M., Usman, A., Jagaba, A. H., & Al-Sabaeei, A. M. (2022). Application and circular economy prospects of palm oil waste for eco-friendly asphalt pavement industry: A review. *Journal of Road Engineering*, *2*(4), 309–331. https://doi.org/10.1016/j.jreng.2022.10.001

Yeoh, W. H., Wong, C. H., Madhavedi, S., & Wolor, C. W. (2025). Sustainable agricultural practices and environmental impact assessment in the

Malaysian palm oil industry for climate change mitigation and biodiversity conservation. *International Journal of Environmental Sciences, 11*(11s), 130–140.

Yue, B., Liu, S., Chai, Y., Wu, G., Guan, N., & Li, L. (2022). Zeolites for separation: Fundamental and application. *Journal of Energy Chemistry, 71*, 288–303. https://doi.org/10.1016/j.jechem.2022.03.035

Zachlod, N., Hudecheck, M., Sirén, C., & George, G. (2025). Sustainable palm oil certification inadvertently affects production efficiency in Malaysia. *Communications Earth and Environment, 6*, 200. https://doi.org/10.1038/s43247-025-02150-2

Zaimi, S. A., Muhd Sidek, M. N., Hashim, N. H., Mohd Saman, H., Putra Jaya, R., & Marzuki, N. A. (2023). Potential of palm oil fuel ash as a partial replacement of fine aggregates for improved fresh and hardened mortar performance. *Advances in Civil Engineering, 2023*, 9064645. https://doi.org/10.1155/2023/9064645

Zainal, Z. S., Hoo, P., Ahmad, A. L., Abdullah, A. Z., Ng, Q., Shuit, S., Enche Ab Rahim, S. K., & Andas, J. (2024). Plant-based calcium silicate from rice husk ash: A green adsorbent for free fatty acid recovery from waste frying oil. *Heliyon, 10*(4), e26591. https://doi.org/10.1016/j.heliyon.2024.e26591

Zelaya, J. R., Ochoa, J. C., & Arias, Y. P. (2017). The use of Colombian palm oil fuel ash in alkali activated cement compressed stabilized earth blocks. *The International Journal of Sustainability Policy and Practice, 13*(2), 19–30. https://doi.org/10.18848/2325-1166/CGP/v13i02/19-30