Automotive Experiences
Vol. 6 No. 3 (2023) pp. 599-623
p-ISSN: 2615-6202 e-ISSN: 2615-6636

Review Paper

Particulate Matter Emission from Combustion and Non-Combustion Automotive Engine Process: Review and Computational Bibliometric Analysis on Its Source, Sizes, and Health and Lung Impact

Asep Bayu Dani Nandiyanto[1], **Risti Ragadhita**[1], **Muji Setiyo**[2,3], **Abdulkareem Sh. Mahdi Al Obaidi**[4], **Arif Hidayat**[5]

[1]Department of Chemistry, Universitas Pendidikan Indonesia, Bandung 40154, Indonesia
[2]Department of Mechanical Engineering, Universitas Muhammadiyah Magelang, Magelang 56172, Indonesia
[3]Center of Energy for Society and Industry, Universitas Muhammadiyah Magelang, Magelang 56172, Indonesia
[4]Department of Mechanical Engineering, Taylor University, Selangor, Malaysia
[5]Department of Chemical Engineering, Universitas Islam Indonesia, Sleman 55584, Indonesia

nandiyanto@upi.edu

https://doi.org/10.31603/ae.10259

Check for updates

Published by Automotive Laboratory of Universitas Muhammadiyah Magelang collaboration with Association of Indonesian Vocational Educators (AIVE)

Article Info
Submitted:
21/09/2023
Revised:
22/10/2023
Accepted:
11/11/2023
Online first:
24/11/2023

Abstract

This study aimed to comprehensively analyze particulate matter (PM) emissions from vehicles, focusing on their sources based on combustion and non-combustion process, classification (PM10, PM2.5, PM0.1), and health implications (including PM transportation into lung). Employing bibliometric analysis, we assessed the growth of scientific publications related to PM, identifying top-cited works based on citations, publisher, author, country, and affiliation. We also visually mapped the development of research in this field using keyword-based publication data from Scopus (2019-2023) with the keywords "particulate matter", "emission", and "particle size" by utilizing Publish or Perish and VOSviewer software. Our findings underscore a significant uptrend in particulate matter research, shedding light on key areas of investigation. This study serves as a valuable resource for academics seeking research direction and a reference point for future investigations.

Keywords: Abrasive; Bibliometric; Combustion; Particulate Matter; Particle Size; Tire; Vehicle; VOSviewer

1. Introduction

Particulate matter (PM) emissions have become a main focal area for environmental protection organizations, which can be from internal combustion engines (ICE) and non-combustion, due to their negative health and environmental effects [1]. PM degrades air quality, contributes to climate change, and causes health problems in humans [2]. PM can have various health effects depending on its transport capabilities and diameter. The transportation industry is a significant contributor to PM pollution in urban environments. Fuel composition, combustion process, and existence of lubricating oil are the three conventional factors causes of light-duty vehicle PM emissions. PM emissions from different sources vary in composition, classified as solid, volatile, or semi-volatile based on physical characteristics, or as organic or inorganic based on chemical content [3]–[5]. Vehicles can emit PM directly during fuel combustion or indirectly through nucleation and condensation in the air during dilution and cooling of hot tailpipe exhaust [6]. The majority of engine combustion particles are graphitic carbon, with minor amounts of metallic ash, sulfur compounds, and hydrocarbons. Particle size distributions and vehicle-emitted PM are influenced by factors such as engine type (SI and CI engines), fuel specifications, particulate filter

technology, vehicle operating conditions (speed, load, and mode), and atmospheric conditions (air temperature, wind speed, and humidity) [5], [7]–[10].

One of the methods for reviewing current literature of PM is bibliometric analysis. Bibliometrics is a rapidly growing and popular discipline that uses mathematics, statistics, and other measurement methods to determine and evaluate the distribution structure, quantitative relationships, change patterns, and quantitative management of literature information based on massive scholarly publications [11]–[13]. Previous papers regarding bibliometric analysis is shown in **Table 1** and **Table 2**.

Bibliometric analysis is classified into two categories. Evaluative techniques/performance analysis is one category, which employs many measures to assess the influence of author/university/country citations on the scientific output of a specific topic. The descriptive nature of the study distinguishes bibliometric research. Performance analysis is used to measure the contributions of research components to a given area [14]. Because reporting the performance of various research components is normal practice in reviews, performance analysis may be found in the majority of reviews, including those that do not participate in scientific mapping [15]. The number of publications and citations, as well as the h-index, are the most often utilized indicators for analysis [16]. Scientific bibliometric mapping/graphic mapping is the second category, and it is designed to portray the dynamic and structural aspects of scientific works and progress [17]–[19]. Science mapping explores the connections between different parts of research [20], with an emphasis on intellectual exchanges and structural linkages between study subjects. Citation analysis, cocitation analysis, bibliographic coupling, co-word analysis, and co-authorship analysis are some of the methodologies utilized in scientific mapping.

Given the limited studies on PM research trends using bibliometrics, this study aimed to analyze the research progress and future directions comprehensively regarding PM emissions from vehicles, focusing on their sources based on combustion and non-combustion process, classification (PM10, PM2.5, PM0.1), and health implications (including PM transportation into lung) (see **Figure 1**). We focused in this field from a macro perspective by identifying and analyzing papers in the Scopus database using bibliometric methods. This study organized extensive data and offer valuable insights to future scholars, enabling a precise analysis of the current situation.

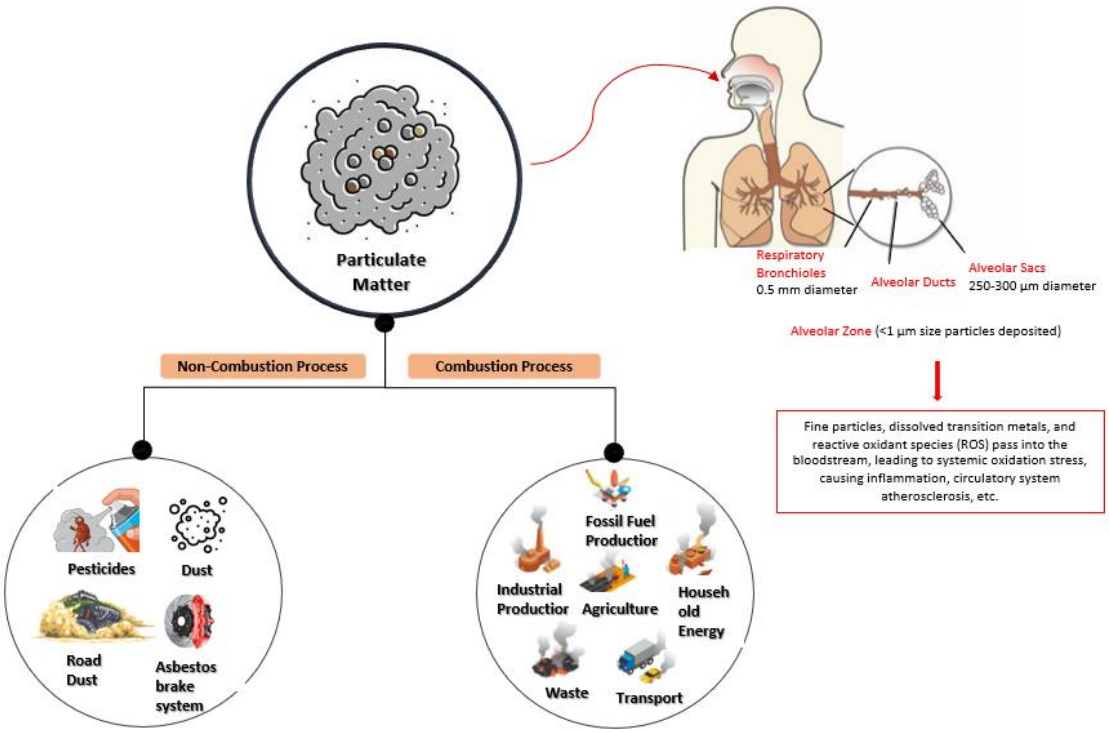

Figure 1. PM classification comes from combustion and non-combustion processes

Table 1. Other previous studies on bibliometric analysis

No	Title	Topic Discussion	Refs.
1	Dental suction aerosol: Bibliometric analysis.	This study used VOSviewer to explain the evolution of dental aerosol suction by distributing bibliometrics maps and research trends.	[21]
2	A bibliometric analysis of Covid-19 researches using VOSViewer.	This study used bibliometric analysis to examine the evolution of research during the Covid-19 era.	[22]
3	The latest report on the advantages and disadvantages of pure biodiesel (B100) on engine performance: Literature review and bibliometric analysis	The literature on the benefits and drawbacks of pure biodiesel on engine performance was reviewed in this study.	[23]
4	A bibliometric analysis of management bioenergy research using VOSviewer application	This study analyzes data on bioenergy management and development over a five-year period (2017-2021) using mapping tools in the VOSViewer.	[24]
5	Oil palm empty fruit bunch waste pretreatment with benzotriazolium-based ionic liquids for cellulose conversion to glucose: Experiments with computational bibliometric analysis	The purpose of this research is to use benzotriazolium salt-ionic liquids (ILs) as solvents in the pretreatment of oil palm empty fruit bunch (EFB) waste, as well as to conduct bibliometric analysis.	[25]
6	Biomass-based supercapacitors electrodes for electrical energy storage systems activated using chemical activation method: A literature review and bibliometric analysis.	This study demonstrates the potential of biomass-based carbon as a highly efficient supercapacitors electrode material useful for obtaining highly efficient current transport for the energy storage system. Various biomass material sources and methods of activation to produce carbon are discussed in depth, with a focus on physical and electrical properties.	[26]
7	Past, current and future trends of salicylic acid and its derivatives: A bibliometric review of papers from the Scopus database published from 2000 to 2021	This study seeks to comprehend the past, present, and future of salicylic acid and its derivatives as a significant substance.	[27]
8	Correlation between process engineering and special needs from bibliometric analysis perspectives	This study is to integrate mapping analysis with the use of the VOSviewer program related “process engineering specific needs".	[28]
9	Bibliometric analysis for understanding the correlation between chemistry and special needs education using VOSviewer indexed by Google.	The purpose of this research is to combine high school mapping with VOSviewer software. The publish or perish reference manager application was used to collect data for this study. To filter the information received, the keywords "Chemistry" and "Special Education" are used.	[29]
10	Nutritional research mapping for endurance sports: A bibliometric analysis.	The keywords used are "Nutrition, Sport, Endurance" and are searched by Google Scholars based on the title and abstract in the publish or perish reference manager to find the mapping of nutritional science research for endurance sports published between 2012 and 2022.	[30]
11	Bibliometric and visualized analysis of scientific publications on geotechnics fields.	This research aims to determine the development of research related to Geotechnical Engineering through a bibliometric distribution map using the VOSviewer application due to geotechnical engineering has a great influence as there is a building on the ground. The facts show that there are still many geotechnical problems that arise during the development process.	[31]
12	A bibliometric analysis of computational mapping on publishing teaching science engineering using VOSviewer application and correlation.	This research examined the description of research developments in science education and engineering.	[32]

No	Title	Topic Discussion	Refs.
13	What is the correlation between chemical engineering and special needs education from the perspective of bibliometric analysis using VOSviewer indexed by Google Scholar?	In this study, the VOSviewer application is used to analyze "Special Needs of Chemical Engineering".	[33]
14	Counselling guidance in science education: Definition, literature review, and bibliometric analysis.	From literary considerations and bibliometric analysis, this study sought to determine the implementation of counselling guidance in science education. One of the most important subjects for increasing student understanding of science and technology is science education. Indeed, the difficulties in science education necessitate the need for some students to seek counseling.	[34]
15	Phytochemical profile and biological activities of ethylacetate extract of peanut (Arachis hypogaea L.) stems: In-vitro and in-silico studies with bibliometric analysis.	This study looked at the chemical content and pharmacological activity of a hypogaea stems in vitro and in silico.	[35]

Table 2. Our previous on bibliometric analysis

No	Title	Topic Discussion	Refs.
1	A bibliometric analysis of materials research in Indonesian journal using VOSviewer	The purpose of this study is to examine the scope of research on materials through a bibliometric review and data mapping process. Materials research data were obtained from databases of selected journals in Indonesia. The search is carried out using a search engine that contains information on all relevant journal articles.	[36]
2	Bibliometric computational mapping analysis of publications on mechanical engineering education using VOSviewer	This study investigates the evolution of mechanical engineering education research using VOSviewer and a bibliometric approach to computational mapping analysis.	[37]
3	Research trend on the use of mercury in gold mining: Literature review and bibliometric analysis	This study used VOSviewer to conduct a bibliometric study on the Google Scholar database to analyze scientific trends in artisanal and small-scale gold mining (ASGM). This study was also completed with an ASGM literature review to support the analysis.	[38]
4	Bibliometric data analysis of research on resin-based brake-pads from 2012 to 2021 using vosviewer mapping analysis computations	The mapping of research bibliometric data analysis related to resin-based brake pads is investigated in this study. The research data was obtained from the Google Scholar database using the publish or perish reference manager application. The title and abstract of the study material are used to search for availability based on the specified keywords, "Resin-based Brake Pads."	[11]
5	Analysis of titanium dioxide nanoparticle synthesis research for photocatalysis using vosviewer	Titanium dioxide (TiO_2) nanoparticles are metal oxide nanoparticles that have gained popularity as photocatalysts in the environment. The goal of this study is to conduct a bibliometric analysis of titanium dioxide nanoparticles synthesis using the mapping analysis function of the VOSviewer software	[39]
6	The role of iron oxide in hydrogen production: Theory and bibliometric analyses	VOSviewer was used to conduct bibliometric studies on the Scopus database to investigate scientific trends in metal oxide oxidation-reduction processes for energy storage systems. Based on the results of harvesting research documents on related topics using the keywords "iron," "hydrogen," "energy," and "oxide"	[40]

No	Title	Topic Discussion	Refs.
		using Publish or Perish in the last ten years (2014-2023), 1980 related research documents were collected and selected from the Scopus database.	
7	A bibliometric analysis of carbon nanotubes synthesis research using VOSviewer	The goal of this study is to combine mapping analysis with VOSviewer software to conduct bibliometric analysis in carbon nanotubes synthesis. Mendeley, an application reference manager, was used to obtain research data. The information obtained is the result of a keyword search for "Synthesis Method of Carbon Nanotubes."	[41]
8	Bibliometric analysis of nano-sized agricultural waste brake pads research during 2018-2022 using VOSviewer	One solution for reducing the risk of asbestos in-vehicle systems is the agricultural brake pad. The goal of this study is to combine mapping analysis with VOSviewer software to perform bibliometric analysis on nano-sized agricultural waste brake pads. To obtain research data, the application reference manager was used. The information obtained is the result of a keyword search for "Brake pads, Nano-sized, Agricultural waste."	[42]
9	Research developments analysis on gold nanoparticles (AuNPS) as antimicrobial agents through bibliometric computational mapping using VOSviewer	The numerous applications of gold nanoparticles in the biomedical field, including as an antimicrobial agent, prompted us to conduct a bibliometric analysis of gold nanoparticles as antimicrobial agents research. Publish or Perish Reference Manager software was used to retrieve publications from the Google Scholar database.	[43]
10	Bibliometric analysis of aluminium oxide nanoparticle in biomedical applications	Aluminium oxide nanoparticles are materials that can be used in a variety of applications, including biomedicine. The goal of this study was to use bibliometric analysis to identify research trends on Al_2O_3 nanoparticles in biomedical applications. The data for this study was obtained from Google Scholar using the Publish or Perish reference manager, and data visualization was done with VOSviewer.	[44]

2. Theory

2.1. Particle Size

There are several sizes of PM in the atmosphere. Particle size is crucial when analyzing engine emissions. The size, origin, and chemical makeup of the particles all influence their properties [7]. Particle size is a common criterion for classifying PM. PM0.1, PM2.5, and PM10 represent ultrafine, fine, and coarse particles, respectively, with aerodynamic dimensions smaller than 0.1, 2.5, and 10 μm [8]. The chemical composition and origins of particles vary in diverse atmospheric conditions. While ultrafine and fine particles constitute a small portion of those produced by combustion sources, they impose a significant environmental impact due to their extended residence time, long-distance transport, and high adsorption capacity for hazardous substances [9].

2.2. The Negative Impact of PM

Particles of differing sizes have different deposition patterns in the human respiratory system as shown in **Figure 2**. The majority of PM10 is deposited in the upper airways due to sedimentation impaction. PM2.5 can be deposited in the lungs and bronchi through sedimentation and Brownian diffusion. Breathing in ultrafine PM0.1 particle allows them to enter the alveoli. There has long been suspicion that ultrafine particles emitted by engines may contribute to various types of cancer. Ultrafine particles can enter the bloodstream and accumulate in organs such as the spleen, liver, or brain, potentially leading to various diseases, including cancer, heart disease, and asthma [10].

Due to the adverse effects of PM on human health, researchers continue to develop methodologies for reducing particulate emissions

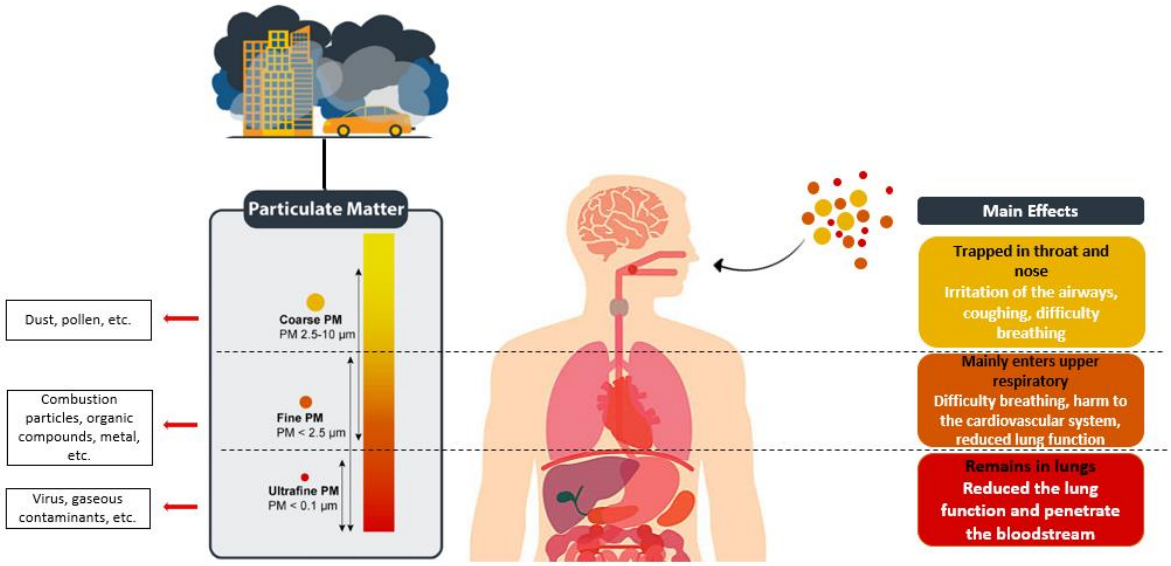

Figure 2. The size, main composition and deposition site in the lung of the particulate matter (PM)

through approaches like fuel modification and post-treatment devices. Consequently, PM characterization and toxicity analysis remain areas of ongoing evolution.

2.3. *Particulate Matter Emission from Combustion Process*

Particulate emissions from combustion have become a significant source of atmospheric pollution. Due to their health and environmental effects, emissions from internal combustion engines (ICE) have become a primary focus for environmental protection agencies [45]. PM degrades air quality, contributes to climate change, and causes health issues in humans. "PM from internal combustion engines is essentially microscopic solid or liquid matter resulting from incomplete fuel oxidation and combustion. In general, the combustion process is conducted to get the advantages: creating energy from the organic resources by converting them into smaller carbon molecules. The main reaction in the combustion process is the conversion of organic resources into volatile matters [46].

The organic resources are composed mainly by hydrocarbon material ($(C_6H_{10}O_5)_n$), and the volatiles are CO, CO_2, H_2, CH_4, C_xH_y, CH_mO_n, and other compounds in traces. To be able to make model for the combustion process, a description of chemical and physical phenomena involved is required. At a chemical level, the combustion process is a vast series of interlinked reactions. To avoid unnecessary complexity in the model, the reaction during the combustion process may be simply described as a one-step first order reaction for the formation of primary product. The simplification of the chemical reaction during the combustion is in reaction (1):

$$(C_xH_yO_z)_n + \text{oxygen} \rightarrow \text{carbon char} + \text{volatiles} + \text{energy} \quad (1)$$

In short, the combustion can create carbon char (forming as PM) and volatiles (can be retransforming into further energy). The volatile itself is defined in Eq (2) and Eq (3):

$$volatiles = \beta_1 gas + \beta_2 gas \quad (2)$$

$$gas = \delta_1 CO + \delta_2 CO_2 + \delta_3 C_x H_y + \delta_4 CH_4 + \delta_5 H_5 \quad (3)$$

All volatile components are neglected since the burning process allows the volatiles to further reactions with oxygen to produce carbon dioxide (CO_2) and water (H_2O). Since the reaction has been set with no limitations in oxygen, and the carbon char formation did not inhibit the burning process, the rate for the formation of carbon char that can further become PM is assumed to have first order of reaction, as shown in Eq (4).

$$\frac{dm_{char}}{dt} = C_D . k . m_{biomass} \quad (4)$$

where m_{char} is the amount of carbon char produced during the combustion (that can further create PM), k is the constant for the combustion, and $m_{biomass}$ is the amount of organic source added for

generating energy in the combustion. C_D is the characteristic constant for the combustion, which is a function of water content and type of engine used. This equation is applied for the mass balance calculation by multiplying with the flow of organic source added into the combustion process. Regarding the k value shown in equation (4), Arhenius approximation (A) can be added into the calculation for the combustion, involving the activation energy for combusting organic resource molecule (E_A) and temperature of combustion (T), as shown in Eq (5).

$$k = A.T.exp\left(\frac{E_A}{RT}\right) \quad (5)$$

where R is the Boltzmann constant. The additional factor in the combustion temperature in equation (5) is due to the exothermic condition involved, in which the combustion process results in the additional heat from the oxidation of organic sources and volatiles. The derivation of equation (4) compared to the thermal gravity analysis results Eq (6).

$$m_{biomass} = \gamma_1.exp(-\gamma_2.T) \quad (6)$$

where γ_1 and γ_1 are the combustion constants. Taken into account the concept of combustion in the release of energy (q_p) as a direct correlation of internal energy (U), the equation can be delivered as Eq (7).

$$\frac{dq_p}{dt} = n.\frac{dU}{dt} \quad (7)$$

where η is the efficiency of the energy transfer from the combustion system, which depends on the utilization of combustion engine and energy transfer tools inside the engine. Adding the heat enthalpy (H_f) during the combustion under a specific condition (i.e. pressure (P) and temperature (T)), Eq (8) can be obtained:

$$dH_f = dU + d(P.V) \quad (8)$$

Therefore, assuming the energy created in the constant pressure and temperature, Eq (9) can be obtained:

$$q_p \approx C_{df}.\Delta H_f \quad (9)$$

where C_{df} is the characteristic constant from the combustion engine for generating electricity.

During the combustion process, most organic resources further oxidize into various intermediate substances and carbon dioxide, while the rest are emitted as solid particle agglomerates (creating PM) [47].

To simplify the PM from combustion, some researchers further categorized them into nucleation and accumulation mode. Nucleation mode particles, typically smaller than 50 nm in diameter, consist of hydrocarbons or sulfates formed during exhaust dilution and cooling. Accumulation mode particles, with sizes ranging from 50 to 1000 nm, mainly consist of carbonaceous soot agglomerates produced during the combustion of fuel-rich regions. The residence time of particles in the atmosphere and their impact are determined by the size and concentration of engine exhaust particulates [48]. PM can have various health impacts depending on its transport abilities and diameter. Particles with sizes ranging from 0.1 to 10 μm can float for a prolonged length of time (up to a week). Particles around 10 μm typically have a residence time of approximately 15 minutes. Larger particles are swiftly removed from the environment through settling, while smaller particles are affected by diffusion and coagulation processes [48].

The transportation sector's emissions are a significant source of PM in urban atmospheres. Fuel composition, combustion richness, and lubrication oil are the three traditional sources of PM emissions from light-duty vehicles. Emissions from these sources are categorized as solid, volatile, or semi-volatile based on their physical state, and as organic or inorganic based on their chemical composition. As mentioned earlier, most engine combustion particles consist of graphitic carbon, with smaller quantities of metallic ash, sulfur compounds, and hydrocarbons. Particle size distributions and vehicle-emitted PM are influenced by various factors, including engine type (spark ignition (SI) and compression ignition (CI) engines, see **Table 3**), fuel specifications, particulate filter technology, vehicle operating conditions (speed, load, and mode), and atmospheric conditions (air temperature, wind speed, and humidity) [49].

2.4. *PM Emission from Non-Combustion Process*

Road traffic emissions contribute to a major share of primary PM within urban areas in both industrialized and developing countries, and an even greater proportion along the roadside. To

Table 3. Different characteristics of engine (SI and CI)

Characteristic	SI Engine (Spark Ignition)	CI Engine (Compression Ignition)
Ignition	Spark plug	Compression of air
Fuel type	Gasoline, CNG, LPG, Hydrogen	Diesel, Biodiesel
Fuel-Air Mixture	Homogeneous	Heterogeneous
Combustion Process	Controlled	Auto-ignition
Power Output	Less torque at low RPM	More torque at low RPM
Efficiency	Lower thermal efficiency	Higher thermal efficiency
Fuel Economy	Lower	Higher
Noise and Vibration	Quieter and smoother	Louder and more vibrations
Emissions	Lower NOx, higher HC and CO	Higher NOx, lower HC and CO
Cold Start	Quick	Slower
Applications	Passenger cars, light vehicles	Trucks, buses, industrial
Fuel Storage	Less energy-dense fuel storage	More energy-dense fuel storage
Maintenance	Simpler and less maintenance	More maintenance
Advantages	• Lower Noise: SI engines tend to be quieter in operation compared to CI engines. • Smooth Operation: They provide smoother and more refined power delivery, ideal for passenger vehicles. • Lighter Weight: SI engines are generally lighter than CI engines, contributing to better fuel efficiency. • Quick Start: They start quickly and can reach their optimal operating temperature faster. • Lower Initial Cost: SI engines are often more cost-effective to manufacture and maintain. • Less Vibrations: They produce fewer vibrations, enhancing driving comfort. • Easier Cold Weather Operation: SI engines perform better in cold weather conditions. • Variety of Fuel Options: SI engines can run on a wide range of fuels, including gasoline, ethanol, and natural gas. • Lower Nitrogen Oxide (NOx) Emissions: SI engines typically emit lower levels of NOx, contributing to better air quality. • Well-suited for Light to Medium-duty Applications: They are commonly used in passenger cars, motorcycles, and smaller power equipment.	• Higher Fuel Efficiency: CI engines are more fuel-efficient than SI engines, resulting in better mileage. • Greater Torque: They produce higher torque at lower RPM, making them suitable for heavy-duty applications. • Longer Engine Life: CI engines typically have a longer lifespan due to robust construction. • Lower CO2 Emissions: They emit fewer carbon dioxide (CO2) emissions per unit of power produced. • Efficient at High Loads: CI engines excel under heavy loads, making them ideal for industrial and commercial use. • Better Fuel Economy: CI engines use less fuel for the same amount of work, reducing operating costs.
Disadvantages	• Lower Thermal Efficiency: SI engines are generally less thermally efficient than CI engines. • Higher Fuel Consumption: They tend to consume more fuel for the same power output compared to CI engines. • Limited Torque at Low RPM: SI engines may lack torque at low revolutions per minute (RPM), affecting their performance in heavy-duty applications. • Higher CO2 Emissions: They can produce higher carbon dioxide (CO2) emissions per unit of power produced. • Knocking: SI engines are prone to knocking when lower-octane fuels are used, potentially damaging the engine. • Shorter Engine Life: They may have a shorter overall lifespan compared to CI engines, especially in high-stress applications.	• CI engines emit higher levels of pollutants, contributing to air and noise pollution, and they rely on finite fossil fuels, raising concerns about sustainability and energy security. • CI engines have complex components leading to higher maintenance needs and potential downtime compared to electric or simpler mechanical systems. • CI engines may have slower startup times, and lower efficiency at low loads, and are impacted by cold weather conditions, affecting responsiveness, fuel consumption, and overall performance. • CI engines are heavier and larger, impacting vehicle design and fuel efficiency.

date, measures to minimize individual vehicle emissions have almost solely concentrated on lowering PM emissions from road cars, with great progress in reducing particle emissions from diesel [50]. To minimize emissions by reducing traffic volume, other non-technological alternatives, such as congestion charge schemes, park-and-ride systems, and automobile-sharing efforts, have also been introduced. Reduced engine emissions have highlighted the fact that PM from non-exhaust sources contributes significantly to airborne concentrations.

The main points in the PM emission generated from non-combustion process is abrasive, causing by several factors [51]:

(i) brake wear,
(ii) tire wear, and
(iii) road surface abrasion.

Frictional contact between brake system components during forced deceleration is a primary source of PM emissions from vehicles. Braking wears out the brake lining components and the brake disc/drum. The composition of the linings used, as well as driving habits, significantly affects the rate of wear, influencing the physical and chemical properties of the released particles. In general, to minimize the impact of the generation of harmless abrasive component, many reports regarding brake system have been well-documented (See **Table 4**).

Table 4. Current studies in the preparation of brake pads using agricultural waste as a reinforcement component

No	Type of agricultural waste	Supporting components	Results	Refs.
1	Rice Husk	Bisphenol A-epichlorohydrin and cycloa-liphaticamine	The interpacking distances, interfacial bonding, and thermal softening of a rice husk particle-resin matrix were all affected by particle size. The compressive strength of the brake pad was improved by small particles. Reduced particle size also resulted in fewer pores, less mass loss, a better wear rate, a higher friction coefficient, and a coarser surface on the brake pad.	[52]
2	Eggshells and Banana Peels	Bisphenol A-epichlorohydrin and cycloa-liphaticamine	The mechanical and frictional properties of brake pads were affected by the dual reinforcement ratio used in their manufacture. Dual reinforcement brake pads outperformed single filers in terms of mechanical and frictional properties. A high BP particle ratio played a dominant role in dual reinforcement, which could increase the resin's bonding ability, resulting in good adhesion between the filler and the matrix. The techno-economic analysis also confirmed the feasibility of producing brake pads from E and BP particles (in comparison to commercial brake pads).	[53]
3	Palm Kernel	Silica, steel slag, silica sand, carbon black, phenolic resin	The role of palm kernel shell (PKS) and silica as friction lining materials among steel slag and phenolic resin particles in the production of automotive brake pads was investigated in this study. As a result, this study concluded that the higher the PKS and lower the silica sand concentrations of the formulated brake pads, the higher the brinell hardness, compressive strength, and wear rate, while decreasing flame resistance, water, and oil absorption.	[54]
4	Walnut Shell	Steel wool, rock wool, and kevlar, phenolic resin, rubber dust, calcium hydroxide, and baryte	The friction composites with walnut shell were designed, fabricated, and tested for physical, mechanical, thermomechanical, and tribological properties. The braking performance was evaluated using the standard test protocol in accordance with the SAE J661 regulation. The physical and mechanical properties of the composites were found to be within industrial standards.	[55]

No	Type of agricultural waste	Supporting components	Results	Refs.
5	Fly ash and Bagasse ash	Phenolic resin, silicon carbide, graphite, barium sulphate	The compressive properties of the phenolic-based composite filled with bagasse ash were slightly higher than those of the fly ash-filled composite, while the other properties were comparable. Taking all of the findings into account, it is possible to conclude that fly ash and bagasse ash have a high potential for use as secondary abrasives in phenolic-based composites for eco-friendly brake pad applications, replacing primary abrasives containing alumina and silica.	[56]
6	Palm fuit fibre and cane wood	Epoxy resin, aluminium oxide, silica, graphite, and iron oxide	A new filler material combination for the production of automobile brake pads has been developed. The best combination of brake pad filler materials - resin, cane wood, and palm fruit fiber - was investigated in this paper. As a result, hybridised cane wood-palm fruit fibres proved to be a good and viable filler material.	[57]
7	Rice Husk/Coco Peat	Acrylonitrile butadiene styrene	The results also revealed that all RH/CP filled composites fractured in a brittle manner. A scanning electron microscope (SEM) examination of the tensile morphology surfaces confirmed the above finding. As a result, it can be concluded that the blend-agriculture waste reinforced ABS biocomposite can be used as a biodegradable material for short-term engineering applications requiring good mechanical and thermal properties.	[58]
8	Cocoa beans shells, maize husk, and palm kernel shells	Silica sand, epoxy resin, calcium carbonate, iron oxide, graphite, and talc.	The obtained results compared favorably with those of conventional brake pads and others produced by similar studies. Specimen analysis revealed that as matrix wt% increases in the formulation, abrasion resistance, friction coefficient, and water soak decrease, while tensile and compressive strength increase. Hardness, density, thermal conductivity, and oil soak, on the other hand, varied non-uniformly with matrix content. The results demonstrated that intermixed particles of the selected agro-wastes could be used as an effective asbestos replacement in friction materials.	[59]
9	Orange peels, coconut, periwinkle, palm kernel and eggshells	Epoxy resin and amine hardener	The new wear rate model is highly efficient and capable of estimating brake pad wear response without underestimating values. As a result, the model can be used to design brake pads. Furthermore, this research can be used to reference other automobile products, such as the brake shoe. The use of dual agro-filler is better than single filler as the complementary properties of the constituent fillers are taken advantage of in a combined form as dual fillers than single filler.	[60]
10	Cocoa Beans Shells	Silica sand, epoxy resin, calcium carbonate, iron oxide, graphite, and talc.	According to the properties of the developed brake pad, decreasing the filler content increased the wear rate, tensile strength, and compressive strength, while hardness, density, water absorption, oil absorption, and thermal conductivity varied. The coefficient of friction increased as the filler wt% increased. The findings indicated that CBS particles could be used effectively as a replacement for asbestos in the manufacture of automotive brake pads.	[61]

Although brake wear is a significant source of PM emissions from traffic, our current understanding of the physical characteristics and chemical composition of brake lining materials and brake wear particles remains incomplete. However, brake linings typically consist of five major components [51], [62]:

(i) Fibers: Mechanical strength is imparted by various types of fibers, including metals, carbon, glass, Kevlar (a trademarked lightweight synthetic fiber known for its exceptional strength and heat resistance), as well as mineral and ceramic fibers. Fibers typically make up between 6% and 35% of the total mass of brake linings.

(ii) Abrasives: These components, usually constituting up to 10% of the lining material, enhance friction, maintain cleanliness between contact surfaces, and prevent the buildup of transfer films. Various materials, such as aluminum oxide, iron oxides, quartz (silicon oxide), and zircon (zirconium silicate), have been employed for this purpose.

(iii) Lubricants: These components, comprising 5 to 29% of the brake lining, play a crucial role in stabilizing frictional properties, particularly at high braking temperatures. Common examples include graphite and other metal sulfides, such as antimony trisulfide (Sb_2S_3).

(iv) Fillers: These substances are added to reduce manufacturing costs and enhance manufacturability. Common examples include barite ($BaSO_4$), calcite ($CaCO_3$), and mica (a silicate mineral group). Fillers can make up anywhere from 15% to 70% of the brake lining composition.

(v) Binders: Essential for maintaining the structural integrity of brake linings during mechanical and thermal stresses. The amount of binder in the lining material varies based on the required performance, typically ranging from 20 to 40%. Phenolic resins are commonly employed as binders.

The experimental results demonstrate that variations in brake lining formulations significantly affect the physical and chemical properties of PM generated by brake abrasion. Brake wear produces particles with diameters ranging from a few hundred nano (nm) to tens of micrometers (μm). While brake wear emissions are primarily the result of a mechanical process, and many researchers would expect them to produce coarse particles, it appears that a significant proportion of brake debris may be emitted in the fine size mode.

Much of the research on the physical properties of brake wear particles has been conducted in brake dynamometer laboratory facilities. Garg et al. in 2000 [63] conducted brake dynamometer tests on seven brake lining formulations commonly used in the US vehicle fleet. Their findings revealed that 86% of the emitted brake particles are PM10, 63% are PM2.5, and 33% are PM0.1. Notably, during testing, only about 35% of the total mass is released from the brake lining into the air and sampled, while the remainder remains trapped in the wheels or brake housing. For coarser particles, sample loss is expected to be even greater.

Sanders et al. in 2003 [64] conducted similar experiments on three brake lining materials, accounting for approximately 90% of the formulations used in the Swedish vehicle fleet. In contrast to Garg et al. in 2000 [63], Sanders et al. in 2003 [64] discovered that the mass of particles emitted during braking was highly dependent on the coating material used, with PM10 accounting for 80% of the emitted particle mass. Both Garg et al. in 2000 [63] and Sanders et al. in 2003 [64] observed and confirmed that material eroded from brake linings was carried into the air, contributing to air pollution.

3. Method

Bibliometric analysis and visualization were employed in this study. The bibliometric analysis employed in this study was descriptive bibliometrics, which characterizes the features of literature. The sample for this study comprises 1,591 publications gathered from the Scopus database using the Publish or Perish software and selected keywords. The data collection for this study spans from 2019 to 2023, and the publications are drawn from various sources, including journal articles, review articles, and books. In this study, the selected keywords are "particulate matter," "emission," and "automotive." Notably, article documents collected are not immediately used for visualization analysis with VOSviewer; rather,

article documents are first subjected to a selection process. Articles lacking essential identity components, such as the year of publication, are excluded. Following the completion of the selection process, the database containing the collection of articles and their identity components is saved in (*csv) and (*ris) formats. The data in (*csv) format is then imported into Microsoft Excel for further analysis. Similarly, the (*ris) format is utilized for visualization analysis with VOSviewer.

The collected data is processed and visualized using the VOSviewer application, which, as mentioned earlier, is software designed for creating and visualizing bibliometrics [40]. This software includes a viewer that facilitates in-depth exploration of bibliometric maps. These maps can be presented in various ways, each emphasizing a different aspect of the data. VOSviewer offers zooming, scrolling, and searching functions, enabling a detailed examination of the maps [10]. The VOSviewer application generates three types of display results: network visualization, overlay visualization, and density visualization.

There are two primary types of bibliometric analysis techniques: performance analysis and mapping [15]. Performance analysis involves assessing metrics such as the number of publications per year, documents with the highest number of citations, institutions with the highest number of citations, journals with the highest number of citations, and shared author keyword usage. Mapping, on the other hand, takes the form of Network Visualization, Overlay Visualization, and Density Visualization. Detailed information for the use of bibliometric analysis is presented in our previous literature [13], [65]–[67].

4. Results and Discussion

4.1. Publication Trend

Figure 3a displays the cumulative and annual publication trends in particulate matter (PM) research from 2019 to 2023. The average number of publications per year during this period is as follows: 565 in 2019, 567 in 2020, 570 in 2021, 511 in 2022, and 366 in 2023. These figures represent respective percentages of the total, which are approximately 21.91%, 21.98%, 22.10%, 19.81%, and 14.19%. It's worth noting that while there was an increase in the publication of articles related to PM research in 2020 and 2021, the growth was relatively modest, with only a 0.08% and 0.12% increase, respectively. However, there has been a significant decline in publications on PM topics after 2021.

As depicted in **Figure 3a**, the peak productivity in this field occurred in 2021, with 570 publications. This demonstrates the increasing importance of research into air pollution and its impact on human health. Conversely, the lowest number of publications was observed in 2023, with only 366 publications. Nevertheless, research related to PM continues to be a vital area within environmental science. This enduring interest is driven by a combination of concerns for public health, environmental consequences, advancements in technology, and policy considerations. While research trends may vary across subfields and regions, the overall trend reflects sustained interest and growth in understanding and addressing PM-related issues [68].

The total annual publications as shown in **Figure 3a** come from the distribution of different document types, including articles, reviews, conference papers, book chapters, editorials,

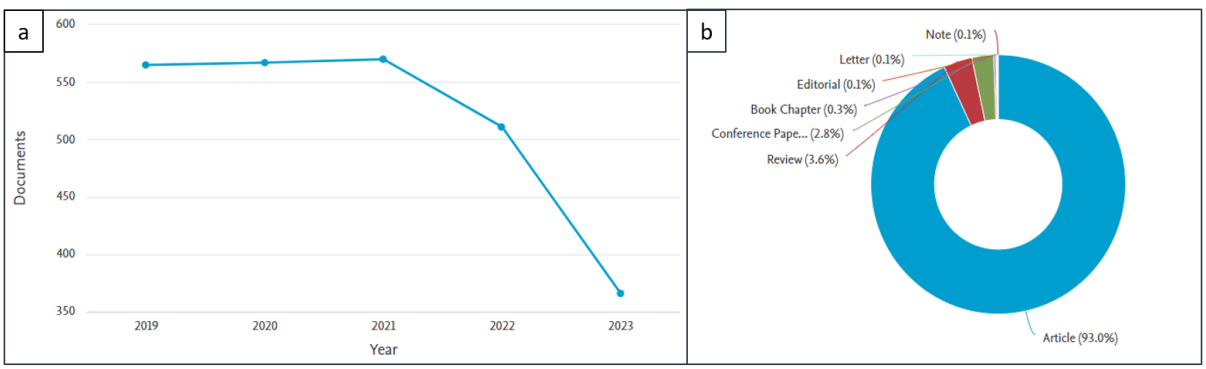

Figure 3. (a) Annual distribution of the number of research publications on PM and (b) Publication type in the field of PM

letters, and notes as shown in **Figure 3b**. Publications related to PM with document types note, letter, and editorial had a presentation of 0.1%. Book chapter, review, and conference paper-type publications each had presentations of 0.3, 289, and 3.6%. Meanwhile, article-type publication documents have the largest percentage, namely more than 93% (see **Figure 3b**).

Figure 3b highlights that articles are the primary type of publication in this field. Consequently, it's natural to have a relatively small proportion of other document types, such as notes, letters, and editorials, which are close to zero in terms of percentage. Articles published in scientific journals are valued for several reasons. They are generally considered trustworthy because they undergo a peer-review process, ensuring accuracy and contributing to the field [68]. Additionally, they often present the first accounts of new research, making their methodology, data, analysis, and interpretation sections primary sources. Furthermore, these articles may include literature reviews and summaries of previous studies related to current research topics, making them valuable secondary sources.

4.2. *Analysis of Citation*

Citations play a crucial role in academic writing and research. They uphold the principles of academic integrity by giving credit to the creators of knowledge, support research arguments, and contribute to building a robust foundation in the broader scientific literature [68]. In addition, citations are the most commonly used method for quantifying the impact and, in some cases, the quality of a publication within a specific field. They also reveal connections between authors, groups of researchers, study topics, or countries [69].

Bibliometric analysis, in particular, provides a valuable metric for assessing overall quality and remains a useful tool for evaluating scientific journals, despite the potential bias introduced by self-citation [70], [71].

In this study, we present ten articles related to various test statistics, collectively accumulating over 150 citations, as shown in **Table 5**. The most cited article in the field of particulate matter (PM) research is "The Impact of Air Pollution on Deaths, Disease Burden, and Life Expectancy Across the States of India: The Global Burden of Disease Study 2017" by Balakrishnan et al. in 2019 with an impressive 648 citations [72]. Additionally, the fifteenth most cited article is titled "Gasoline Automobile Catalysis and its Historical Journey to Cleaner Air," authored by Farrauto et al. in 2019, boasting 153 citations [73].

4.3. *Analysis of Subject Distribution*

Bibliometric subject distribution is a valuable technique for identifying scientific disciplines that contribute to the development of research fields. **Figure 4** illustrates the results of subject distribution in research related to particulate matter (PM). These publications are distributed across 23 subject areas, and a detailed breakdown of the number of documents in each subject area is presented in **Table 6**.

As depicted in **Figure 4** and detailed in **Table 6**, five subject areas host the most research related to PM: environmental science, earth and planetary sciences, chemistry, engineering, and medicine, with respective totals of 1232, 248, 207, 204, and 182 documents. These subject areas, based on the number of articles published, are the most significant contributors to PM research. Conversely, subject areas such as dentistry, nursing, and psychology appear to have relatively less involvement in this research.

Environmental science is particularly well-suited for PM research because it addresses topics related to the environment, where PM pollution contributes to issues such as acid rain and climate change [1]–[5]. Beyond exacerbating acid rain, particulate pollution can also influence weather patterns, induce droughts, contribute to global warming, and lead to ocean acidification.

4.4. *Analysis by Author*

Core authors within an academic community play a crucial role in driving the development of a discipline. They help researchers identify potential collaborators and gain insights into how their research aligns with related work. **Figure 5** presents the top 10 most prolific researchers in the field of particulate matter (PM) research worldwide. Among them, two researchers have authored over 20 documents each, namely Ronkko and Timonen. Additionally, Feng, Harrison, and Saarikoski are notable researchers

with more than 15 articles each. Furthermore, there are authors with more than 10 articles to their name, including Hopke, Querol, Cao, Keskinen, and Siotas.

Table 5. Top 15 most cited articles

No	Cites	Title	Year	CitesPer Year	CitesPer Author
1	648	The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: the Global Burden of Disease Study 2017	2019	162	162
2	531	IJER editorial: The future of the internal combustion engine	2020	177	106
3	468	Inequity in consumption of goods and services adds to racial–ethnic disparities in air pollution exposure	2019	117	117
4	299	Air quality during the COVID-19: PM2. 5 analysis in the 50 most polluted capital cities in the world	2020	99.67	150
5	278	Ultrafine particles: unique physicochemical properties relevant to health and disease	2020	92.67	93
6	272	Health and economic impact of air pollution in the states of India: the Global Burden of Disease Study 2019	2021	136	68
7	241	A review on clean ammonia as a potential fuel for power generators	2019	60.25	121
8	239	Association of particulate matter pollution and case fatality rate of COVID-19 in 49 Chinese cities	2020	79.67	34
9	214	The relationship between air pollution and COVID-19-related deaths: an application to three French cities	2020	71.33	71
10	203	Review of thermal management of catalytic converters to decrease engine emissions during cold start and warm up	2019	50.75	41
11	184	A review on regulations, current status, effects and reduction strategies of emissions for marine diesel engines	2020	61.33	61
12	164	Vehicle emissions trapping materials: Successes, challenges, and the path forward	2019	41	55
13	161	A review of the current automotive manufacturing practice from an energy perspective	2020	53.67	32
14	155	A comparative study on methanol/diesel and methanol/PODE dual fuel RCCI combustion in an automotive diesel engine	2020	51.67	52
15	153	Gasoline automobile catalysis and its historical journey to cleaner air	2019	38.25	51

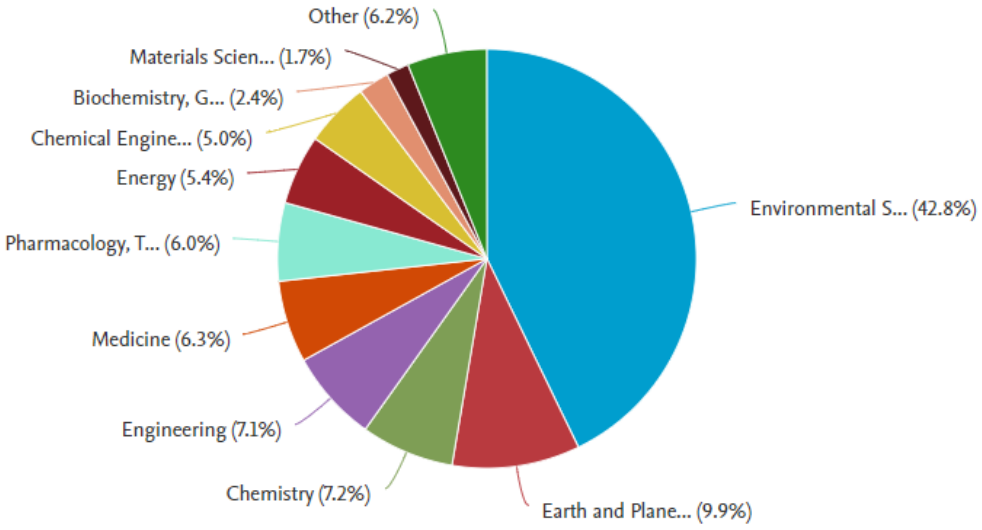

Figure 4. Subject area distribution related PM study

Table 6. Detailed distribution regarding the number of documents in each subject area

Subject Area	Documents
Environmental Science	1232
Earth and Planetary Sciences	248
Chemistry	207
Engineering	204
Medicine	182
Pharmacology, Toxicology and Pharmaceutics	174
Energy	155
Chemical Engineering	144
Biochemistry, Genetics and Molecular Biology	69
Materials Science	50
Physics and Astronomy	47
Agricultural and Biological Sciences	28
Social Science	24
Computer Science	21
Mathematics	16
Multidisciplinary	16
Immunology and Microbiology	28
Business, Management and Accounting	8
Economics, Econometrics and Finance	8
Immunology and Microbiology	2
Dentistry	1
Nursing	1
Physiology	1

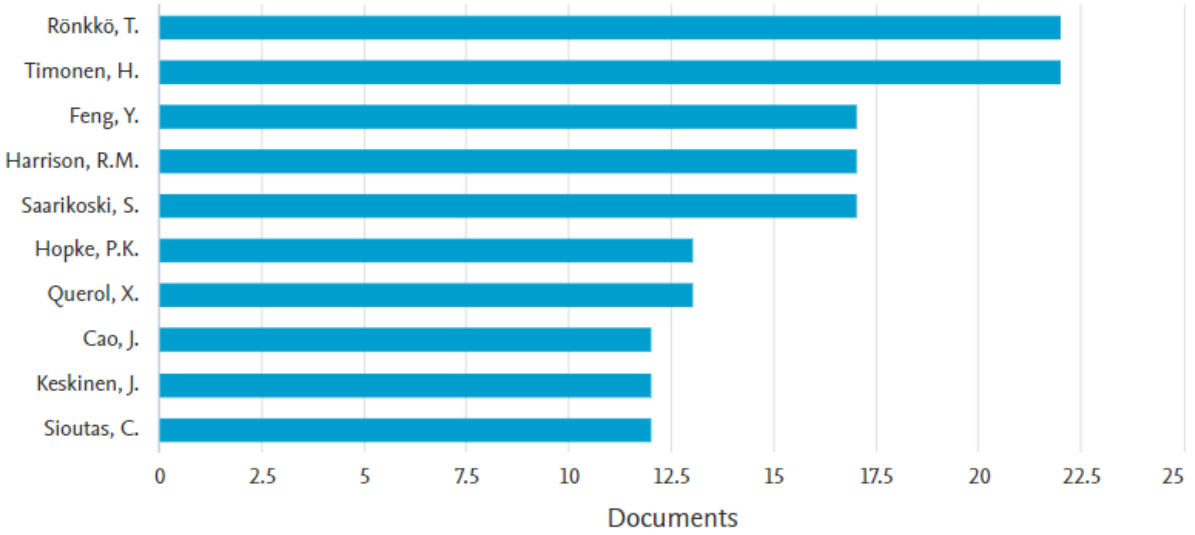

Figure 5. Most relevant authors by total documents in PM research across subject areas

4.5. Analysis by Country

Analyzing the number of articles published in different countries provides valuable insights into each country's contribution to the field of particulate matter (PM) research. **Figure 6** illustrates the spatial distribution of published papers on PM research across various countries. According to **Figure 6**, the countries with the highest number of publications are as follows: China (611 articles, 38.40%), the United States (320 articles, 20.11%), England (115 articles, 7.22%), Italy (105 articles, 6.59%), and Germany (94 articles, 5.91%). These five countries, ranked first through fifth, lead in PM research, indicating that the majority of prominent research groups and practitioners are concentrated in these regions.

4.6. Analysis by Affiliation

Publication affiliations play a pivotal role in establishing the credibility of authors, promoting collaboration, and ensuring transparency in research. They offer essential context and

background information that allows readers and researchers to evaluate the quality and relevance of published work [74]–[78].

Table 7 presents a list of the top 10 affiliations with the highest number of documents in the field of particulate matter (PM) research. Leading the list is the Chinese Academy of Sciences, with the most extensive collection of related research documents totaling 108. Following closely is the Ministry of Education of the People's Republic of China, ranking second, and the University of Chinese Academy of Sciences in third place.

This analysis by affiliation underscores China's significant progress across various research domains, highlighting its growing prominence on the global research stage. However, it's crucial to acknowledge that the global research landscape is dynamic and subject to change over time. Factors such as government policies, economic conditions, and geopolitical dynamics can influence shifts in research dominance across fields [79]. Therefore, it's essential to consider the latest data and developments to assess China's continued prominence in research, both in 2023 and beyond.

4.7. Network and Overlay Visualization

Using VOSviewer for co-occurrence analysis, we visually mapped author keywords, creating networked representations displayed in **Figure 7a** and **Figure 7b**. To maintain a manageable set of keywords for visualization, we retained only words that appeared at least 10 times. This process resulted in a total of 70 words organized into three distinct groups, highlighted in red, green, and blue (refer to **Figure 7a**).

In this visualization, clusters represent sets of closely related nodes, with frequently occurring terms positioned closer to one another [13]. The formation of these clusters employed the strength of association approach, ensuring that clusters contained a minimum of 117 elements to enhance the analysis and reduce smaller clusters [10].

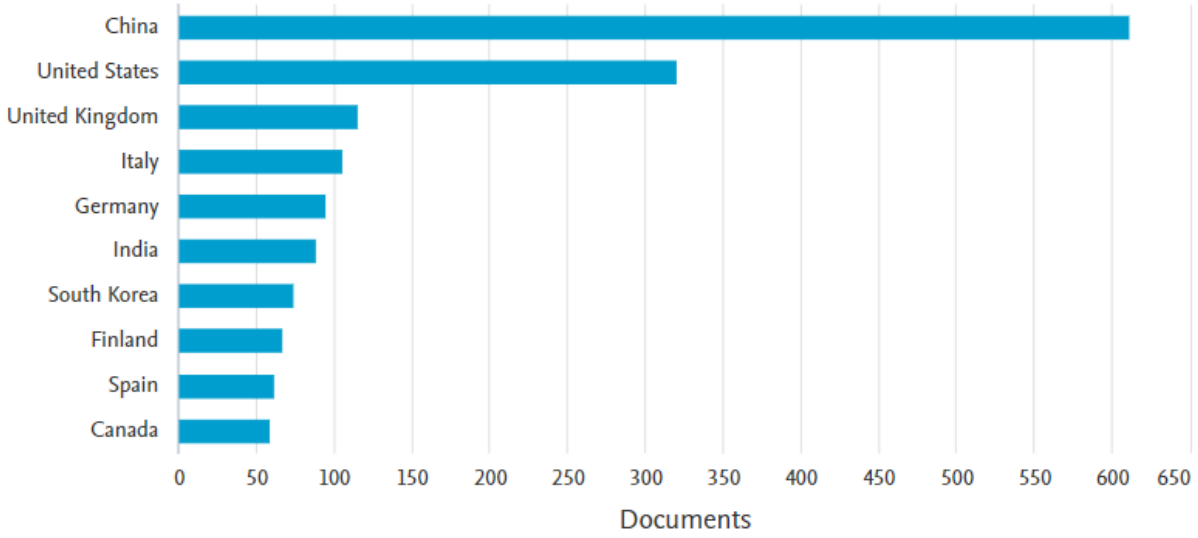

Figure 6. Top 10 countries for research on PM

Table 7. Top 10 affiliations for research on PM

Affiliation	Documents
Chinese Academy of Sciences	108
Ministry of Education of the People's Republic of China	65
University of Chinese Academy of Sciences	50
Nanjing University of Information Science & Technology	41
Tsinghua University	39
Finnish Meteorological Institute	33
Peking University	32
Nankai University	32
University of Birmingham	32
Xi'an Jiaotong University	31

The subsequent sections provide a narrative summary of key themes and patterns within each cluster.

Cluster 1, marked in red, is centered around the keyword "matter" and exhibits a total link strength of 1305 with 651 occurrences. This cluster encompasses various relationships with terms such as "airborne particulate matter," "air pollution role," "fine particulate matter," and "atmospheric particulate." Cluster 1 underscores the significance of particulate matter (PM) as a crucial air pollutant, particularly concerning its impacts on human health.

Numerous epidemiological studies have consistently established a substantial association between PM concentrations in the air and adverse health outcomes [1]–[3]. Among the different categories of PM, fine particulate matter stands out as a significant contributor to the observed health impacts, primarily due to its ability to accumulate and penetrate the lower respiratory system.

While the effects of PM can vary depending on factors like composition and size distribution, in general, exposure to inhaled PM can result in several adverse outcomes. These include increased rates of cardiac and respiratory mortality, decreased lung function in both children and adults with obstructive airways disease, heightened prevalence of respiratory symptoms in children and adults, elevated functional limitations, as evidenced by school absences or restricted activity days, and an increased frequency of physician and emergency room visits for conditions such as asthma and other respiratory ailments [4], [5].

Cluster 2, highlighted in green, centers around the primary keyword 'diesel engine' and exhibits a total link strength of 3343 with 116 occurrences. Within this cluster, you'll find several related terms, including 'carbon dioxide emission,' 'CI engine,' 'exhaust gas,' 'fuel consumption,' 'hydrocarbon,' 'NOx,' and 'CO_2.'

Cluster 2 predominantly deals with particles emitted from diesel engines that are fueled by residual oil, encompassing various compositions and sizes of particulate matter (PM). While the significance of these emissions, both as air pollutants and contributors to climate change, is well-established, comprehensive information regarding engine exhaust particle emissions remains crucial. This includes a detailed characterization of chemical composition and microphysical characteristics, involving elements, organic and inorganic carbon, sulfate, ash, and nitrate.

Moreover, diesel engine combustion has a substantial local impact on surrounding air quality, particularly due to emissions of NOx, SO_2, PM, and VOCs (volatile organic compounds) [47], [48].

Cluster 3, depicted in blue, exhibits a total link strength of 3343 with an occurrence of 40 terms. Key terms within this cluster include 'temperature,' 'particulate filter,' and 'chemical composition.' These terms are closely related to the complex field of particulate matter (PM) emissions, which are influenced by various factors, including temperature.

PM emissions result from a series of physical processes such as evaporation, condensation, fragmentation, and chemical reactions involving inorganic mineral components and organically bound metal compounds in solid fuels. Existing literature indicates that coarse particle emissions from coal combustion tend to be higher compared to biomass emissions, whereas ultrafine and fine particle emissions from biomass burning often surpass those from coal combustion [80].

Several factors influence particle emissions, including the particle size of solid fuel, inherent ash content, mineral properties, the binding form of inorganic elements, combustion parameters (temperature, pressure, residence time, oxygen concentration, etc.), and the chemical composition of the ash [80]. These intricate interactions contribute to the complex nature of PM emissions and necessitate thorough investigation.

Figure 7b depicts a cluster analysis employing keyword terms to identify the most common and less common research subjects worldwide. An overlay network visualization is employed to illustrate emerging themes. The overlay visualization network highlights topics or keywords relevant to the research, organized by the year of publication. Notably, in 2020, terms such as 'compression ignition engine,' 'emission,' 'combustion,' 'air quality,' and 'fine particulate matter' (represented by yellow nodes) did not receive intensive study (see **Figure 7b**).

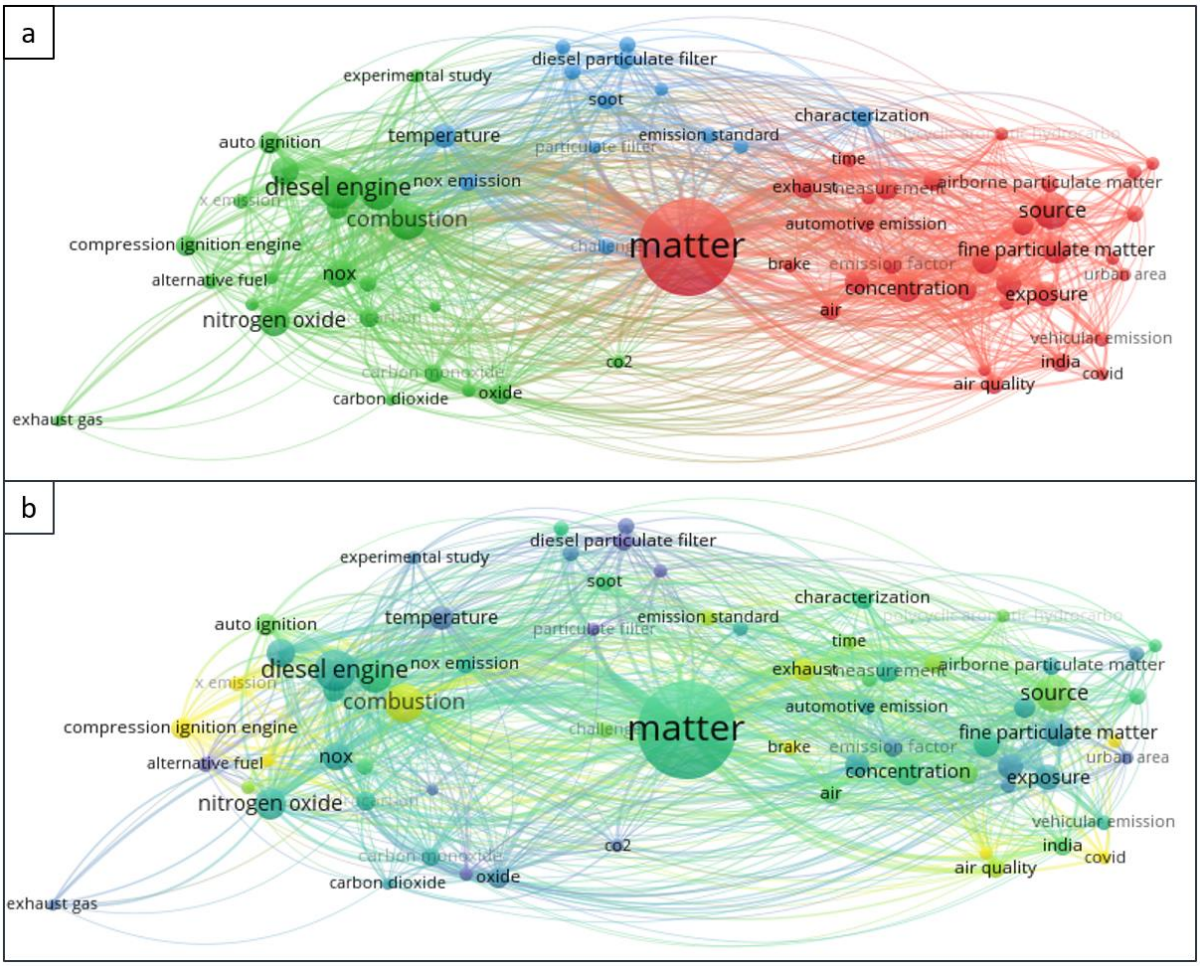

Figure 7. Research on PM visualized by VOSviewer: (a) Network visualization and (b) Overlay visualization

4.8. Future Direction

This study is important for adding new ideas and suggestions regarding the use of engine system in automotive, as reported by several researchers for showing the controlling combustion [81], [82], results of combustion in the formation of carbon dioxide [83] and carbon black [84], and the use of alternative energy [85] such as LPG [86]–[88] and biodiesel [23], [89]–[92], as well as other PM sources from industry such as cement industry [93]–[95].

5. Conclusion

This paper review current literature on PM emissions. We comprehensively analyze PM emissions from vehicles, focusing on their sources based on combustion and non-combustion process, classification (PM10, PM2.5, PM0.1), and health implications (including PM transportation into lung). The research findings shed light on the critical importance of advancing research in PM emissions and particle size, especially within Scopus-indexed publications. This analysis encompasses various aspects of the field, providing valuable insights into the current state of research on particulate matter.

(i) High Publication Volume in 2021: In 2021, there was a significant surge in research publications related to particulate matter, totaling 570 publications (22.10% of the total), encompassing various document types, including articles, reviews, conference papers, book chapters, editorials, letters, and notes.

(ii) Top-Cited Articles: An analysis of top-cited articles revealed that 15 articles in this field have garnered substantial attention, each amassing more than 150 citations, indicating their significant impact and relevance.

(iii) Prominent Journals: The journals that stand out as major contributors to PM research include those in the fields of environmental science, earth and planetary sciences, chemistry, engineering, and medicine.

(iv) Prolific Author: Among researchers, Ronkko emerges as the most prolific author in the area of particulate matter research, indicating substantial contributions to the field.
(v) Leading Countries and Organizations: China, particularly represented by the Chinese Academy of Sciences, takes the lead in contributing to PM research, both in terms of publications and organizational affiliations.
(vi) Keyword Analysis: A network visualization analysis highlights the most frequently used keyword, "emission," indicating a central focus in PM research. Conversely, "experimental study" is the least frequently used keyword.
(vii) Recent Research Trends in 2023: The most recent research trends in 2023 reveal a concentration of studies on keywords such as "emission," "diesel engine," "matter," "combustion," and "characterization," indicating the evolving areas of interest.
(viii) Research Aid and Reference: This comprehensive research is expected to serve as a valuable resource for researchers, aiding in the identification of critical research areas and providing a reference point for future investigations in the realm of particulate matter.

Acknowledgement

We acknowledge Universitas Pendidikan Indonesia.

Author's Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

Funding

No funding information from the authors.

Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

Additional information

No additional information from the authors.

References

[1] P. Geng, H. Zhang, and S. Yang, "Experimental investigation on the combustion and particulate matter (PM) emissions from a port-fuel injection (PFI) gasoline engine fueled with methanol–ultralow sulfur gasoline blends," *Fuel*, vol. 145, pp. 221–227, 2015, doi: 10.1016/j.fuel.2014.12.067.
[2] J. R. Marlon *et al.*, "How hope and doubt affect climate change mobilization," *Frontiers in Communication*, vol. 4, p. 20, 2019, doi: 10.3389/fcomm.2019.00020.
[3] N. K. Gali, F. Yang, C. S. Cheung, and Z. Ning, "A comparative analysis of chemical components and cell toxicity properties of solid and semi-volatile PM from diesel and biodiesel blend," *Journal of Aerosol Science*, vol. 111, pp. 51–64, 2017, doi: 10.1016/j.jaerosci.2017.06.005.
[4] S. Dey and N. S. Mehta, "Automobile pollution control using catalysis," *Resources, Environment and Sustainability*, vol. 2, p. 100006, 2020, doi: 10.1016/j.resenv.2020.100006.
[5] O. I. Awad, X. Ma, M. Kamil, O. M. Ali, Z. Zhang, and S. Shuai, "Particulate emissions from gasoline direct injection engines: A review of how current emission regulations are being met by automobile manufacturers," *Science of the Total Environment*, vol. 718, p. 137302, 2020, doi: 10.1016/j.scitotenv.2020.137302.
[6] A. Zare *et al.*, "Hazardous particles during diesel engine cold-start and warm-up: Characterisation of particulate mass and number under the impact of biofuel and lubricating oil," *Journal of Hazardous Materials*, vol. 460, p. 132516, 2023, doi: 10.1016/j.jhazmat.2023.132516.
[7] M. Vijay Kumar *et al.*, "Impact of a Thermal Barrier Coating in Low Heat Rejection Environment Area of a Diesel Engine," *Sustainability*, vol. 14, no. 23, p. 15801, 2022, doi: 10.3390/su142315801.
[8] T. T. Huyen *et al.*, "Characteristics of chemical components in fine particles (PM2. 5) and ultrafine particles (PM0. 1) in Hanoi, Vietnam: a case study in two seasons with different humidity," *Water, Air, & Soil Pollution*, vol. 232, no. 5, p. 183, 2021, doi:

10.1007/s11270-021-05108-0.

[9] M. U. Ali, G. Liu, B. Yousaf, H. Ullah, Q. Abbas, and M. A. M. Munir, "A systematic review on global pollution status of particulate matter-associated potential toxic elements and health perspectives in urban environment," *Environmental geochemistry and health*, vol. 41, pp. 1131–1162, 2019, doi: 10.1007/s10653-018-0203-z.

[10] N. Manojkumar, B. Srimuruganandam, and S. M. S. Nagendra, "Application of multiple-path particle dosimetry model for quantifying age specified deposition of particulate matter in human airway," *Ecotoxicology and Environmental Safety*, vol. 168, pp. 241–248, 2019, doi: 10.1016/j.ecoenv.2018.10.091.

[11] A. B. D. Nandiyanto, D. F. Al Husaeni, and R. Ragadhita, "Bibliometric data analysis of research on resin-based brake-pads from 2012 to 2021 using vosviewer mapping analysis computations," *ASEAN Journal for Science and Engineering in Materials*, vol. 2, no. 1, pp. 35–44, 2023, [Online]. Available: https://ejournal.bumipublikasinusantara.id/index.php/ajsem/article/view/112.

[12] A. B. D. Nandiyanto, D. F. Al Husaeni, and D. N. Al Husaeni, "Social Impact and Internationalization of 'Indonesian Journal of Science and Technology' the Best Journal in Indonesia: A Bibliometric Analysis," *Journal of Advanced Research in Applied Sciences and Engineering Technology*, vol. 32, no. 2, pp. 42–59, 2023, doi: 10.37934/araset.32.2.4259.

[13] D. F. Al Husaeni and A. B. D. Nandiyanto, "Bibliometric using Vosviewer with Publish or Perish (using google scholar data): From step-by-step processing for users to the practical examples in the analysis of digital learning articles in pre and post Covid-19 pandemic," *ASEAN Journal of Science and Engineering*, vol. 2, no. 1, pp. 19–46, 2022, doi: 10.17509/ajse.v2i1.37368.

[14] M. J. Cobo, A. G. López-Herrera, E. Herrera-Viedma, and F. Herrera, "Science mapping software tools: Review, analysis, and cooperative study among tools," *Journal of the American Society for information Science and Technology*, vol. 62, no. 7, pp. 1382–1402, 2011, doi: 10.1002/asi.21525.

[15] N. Donthu, S. Kumar, D. Mukherjee, N. Pandey, and W. M. Lim, "How to conduct a bibliometric analysis: An overview and guidelines," *Journal of Business Research*, vol. 133, p. 2850296, 2021, doi: 10.1016/j.jbusres.2021.04.070.

[16] M. Mishra *et al.*, "An overview of research on natural resources and indigenous communities: a bibliometric analysis based on Scopus database (1979–2020)," *Environmental Monitoring and Assessment*, vol. 193, pp. 1–17, 2021, doi: 10.1007/s10661-020-08793-2.

[17] M. A. Koseoglu, "Growth and structure of authorship and co-authorship network in the strategic management realm: Evidence from the Strategic Management Journal," *BRQ Business Research Quarterly*, vol. 19, no. 3, pp. 153–170, 2016, doi: 10.1016/j.brq.2016.02.001.

[18] S. Laengle *et al.*, "Forty years of the European Journal of Operational Research: A bibliometric overview," *European Journal of Operational Research*, vol. 262, no. 3, pp. 803–816, 2017, doi: 10.1016/j.ejor.2017.04.027.

[19] J. M. Merigó, W. Pedrycz, R. Weber, and C. de la Sotta, "Fifty years of Information Sciences: A bibliometric overview," *Information Sciences*, vol. 432, pp. 245–268, 2018, doi: 10.1016/j.ins.2017.11.054.

[20] L. Waltman, N. J. Van Eck, and E. C. M. Noyons, "A unified approach to mapping and clustering of bibliometric networks," *Journal of informetrics*, vol. 4, no. 4, pp. 629–635, 2010, doi: 10.1016/j.joi.2010.07.002.

[21] D. F. Ramadhan, A. M. Fabian, and H. M. Saputra, "Dental suction aerosol: Bibliometric analysis," *ASEAN Journal of Science and Engineering*, vol. 2, no. 3, pp. 295–302, 2022, [Online]. Available: https://ejournal.upi.edu/index.php/AJSE/article/view/50658/20174.

[22] I. Hamidah, S. Sriyono, and M. N. Hudha, "A Bibliometric analysis of Covid-19 research using VOSviewer," *Indonesian Journal of Science and Technology*, vol. 5, no. 2, pp. 34–41, 2020, doi: 10.17509/ijost.v5i2.24522.

[23] M. Setiyo, D. Yuvenda, and O. D. Samuel, "The concise latest report on the advantages and disadvantages of pure biodiesel (B100) on engine performance: literature review and bibliometric analysis," *Indonesian Journal of Science and Technology*, vol. 6, no. 3, pp. 469–

490, 2021, doi: 10.17509/ijost.v6i3.38430.

[24] H. Soegoto, E. S. Soegoto, S. Luckyardi, and A. A. Rafdhi, "A Bibliometric Analysis of Management Bioenergy Research Using Vosviewer Application," *Indonesian Journal of Science and Technology*, vol. 7, no. 1, pp. 89–104, 2022, doi: 10.17509/ijost.v7i1.43328.

[25] A. Mudzakir, K. M. Rizky, H. S. H. Munawaroh, and D. Puspitasari, "Oil palm empty fruit bunch waste pretreatment with benzotriazolium-based ionic liquids for cellulose conversion to glucose: Experiments with computational bibliometric analysis," *Indonesian Journal of Science and Technology*, vol. 7, no. 2, pp. 291–310, 2022, doi: 10.17509/ijost.v7i2.50800.

[26] I. Hamidah *et al.*, "Biomass-based supercapacitors electrodes for electrical energy storage systems activated using chemical activation method: A Review," *Indonesian Journal of Science and Technology*, vol. 8, no. 3, pp. 439–468, 2023, doi: 10.17509/ijost.v8i3.60688.

[27] A. Ruzmetov and A. Ibragimov, "Past, current and future trends of salicylic acid and its derivatives: A bibliometric review of papers from the Scopus database published from 2000 to 2021," *ASEAN Journal for Science and Engineering in Materials*, vol. 2, no. 1, pp. 53–68, 2023, [Online]. Available: https://ejournal.bumipublikasinusantara.id/index.php/ajsem/article/view/225.

[28] N. A. H. M. Nordin, "Correlation between process engineering and special needs from bibliometric analysis perspectives," *ASEAN Journal of Community and Special Needs Education*, vol. 1, no. 1, pp. 9–16, 2022, [Online]. Available: https://ejournal.bumipublikasinusantara.id/index.php/ajcsne/article/view/3.

[29] M. R. Bilad, "Bibliometric analysis for understanding the correlation between chemistry and special needs education using vosviewer indexed by google," *ASEAN Journal of Community and Special Needs Education*, vol. 1, no. 2, pp. 61–68, 2022, [Online]. Available: https://ejournal.bumipublikasinusantara.id/index.php/ajcsne/article/view/61.

[30] I. R. Firdaus, M. F. Febrianty, P. N. Awwaludin, M. N. F. Ilsya, Y. Nurcahya, and K. Sultoni, "Nutritional research mapping for endurance sports: A bibliometric analysis," *ASEAN Journal of Physical Education and Sport Science*, vol. 2, no. 1, pp. 23–38, 2023, [Online]. Available: https://ejournal.bumipublikasinusantara.id/index.php/ajopess/article/view/198.

[31] I. B. Mulyawati and D. F. Ramadhan, "Bibliometric and visualized analysis of scientific publications on geotechnics fields," *ASEAN Journal of Science and Engineering Education*, vol. 1, no. 1, pp. 37–46, 2021, doi: 10.17509/ajsee.v1i1.32405.

[32] N. A. H. M. Nordin, "A bibliometric analysis of computational mapping on publishing teaching science engineering using VOSviewer application and correlation," *Indonesian Journal of Teaching in Science*, vol. 2, no. 2, pp. 127–138, 2022, doi: 10.17509/ijotis.v2i2.47038.

[33] M. D. H. Wirzal and Z. A. Putra, "What is the correlation between chemical engineering and special needs education from the perspective of bibliometric analysis using vosviewer indexed by google scholar," *Indonesian Journal of Community and Special Needs Education*, vol. 2, no. 2, pp. 103–110, 2022, doi: 10.17509/ijcsne.v2i2.44581.

[34] M. Solehuddin, M. Muktiarni, N. I. Rahayu, and R. Maryanti, "Counseling guidance in science education: Definition, literature review, and bibliometric analysis," *Journal of Engineering Science and Technology*, vol. 18, pp. 1–13, 2023.

[35] I. Sahidin *et al.*, "Phytochemical profile and biological activities of ethylacetate extract of peanut (Arachis hypogaea L.) stems: In-vitro and in-silico studies with bibliometric analysis," *Indonesian Journal of Science and Technology*, vol. 8, no. 2, pp. 217–242, 2023, doi: 10.17509/ijost.v8i2.54822.

[36] A. B. D. Nandiyanto and D. F. Al Husaeni, "A bibliometric analysis of materials research in Indonesian journal using VOSviewer," *Journal of Engineering Research*, vol. ASSEEE, no. Special Issue, pp. 1–16, 2021, doi: 10.36909/jer.ASSEEE.16037.

[37] D. F. Al Husaeni and A. B. D. Nandiyanto, "Bibliometric computational mapping analysis of publications on mechanical engineering education using vosviewer,"

Journal of Engineering Science and Technology, vol. 17, no. 2, pp. 1135–1149, 2022.

[38] A. B. D. Nandiyanto, R. Ragadhita, D. N. Al Husaeni, and W. C. Nugraha, "Research trend on the use of mercury in gold mining: Literature review and bibliometric analysis," *Moroccan Journal of Chemistry*, vol. 11, no. 1, p. 11, 2023, doi: 10.48317/IMIST.PRSM/morjchem-v11i1.36576.

[39] E. R. Nugraha and A. B. D. Nandiyanto, "Bibliometric Analysis of Titanium Dioxide Nanoparticle Synthesis Research for Photocatalyst Using Vosviewer," *Open Soil Science and Environment*, vol. 1, no. 1, pp. 8–14, 2022, doi: 10.33292/osse.v1i1.2.

[40] A. B. D. Nandiyanto, R. Ragadhita, M. Fiandini, D. N. Al Husaeni, and M. Aziz, "The Role of Iron Oxide in Hydrogen Production: Theory and Bibliometric Analyses," *Moroccan Journal of Chemistry*, vol. 11, no. 04, pp. 11–14, 2023, doi: 10.48317/IMIST.PRSM/morjchem-v11i04.41591.

[41] A. Aldhafi and A. B. D. Nandiyanto, "A Bibliometric Analysis of Carbon Nanotubes Synthesis Research Using Vosviewer," *International Journal of Research and Applied Technology (INJURATECH)*, vol. 1, no. 2, pp. 76–81, 2021, doi: 10.34010/injuratech.v1i2.6404.

[42] S. Deni and A. B. D. Nandiyanto, "Bibliometric analysis of nano-sized agricultural waste brake pads research during 2018-2022 using Vosviewer," *International Journal of Sustainable Transportation Technology*, vol. 5, no. 1, pp. 12–17, 2022, doi: 10.31427/IJSTT.2022.5.1.2.

[43] T. M. S. Erlangga and A. B. D. Nandiyanto, "Research Developments Analysis on Gold Nanoparticles (AuNPS) as Antimicrobial Agents through Bibliometric Computational Mapping using VOSviewer," *Fullerene Journal of Chemistry*, vol. 7, no. 2, pp. 101–110, 2023, doi: 10.37033/fjc.v7i2.462.

[44] Z. Rufaida and A. B. D. Nandiyanto, "Bibliometric Analysis of Aluminium Oxide Nanoparticle in Biomedical Applications," *Advance Sustainable Science Engineering and Technology*, vol. 4, no. 2, p. 220203, 2022, doi: 10.26877/asset.v4i2.13336.

[45] K. R. Daellenbach *et al.*, "Sources of particulate-matter air pollution and its oxidative potential in Europe," *Nature*, vol. 587, no. 7834, pp. 414–419, 2020, doi: 10.1038/s41586-020-2902-8.

[46] C. Peng *et al.*, "Production of char from sewage sludge employing hydrothermal carbonization: char properties, combustion behavior and thermal characteristics," *Fuel*, vol. 176, pp. 110–118, 2016, doi: 10.1016/j.fuel.2016.02.068.

[47] B. Alahmad, H. Khraishah, K. Althalji, W. Borchert, F. Al-Mulla, and P. Koutrakis, "Connections between air pollution, climate change, and cardiovascular health," *Canadian Journal of Cardiology*, vol. 39, no. 9, pp. 1182–1190, 2023, doi: 10.1016/j.cjca.2023.03.025.

[48] K. Rajagopal, S. Ramachandran, and R. K. Mishra, "Roadside measurements of nanoparticles and their dynamics in relation to traffic sources in Delhi: Impact of restrictions and pollution events," *Urban Climate*, vol. 51, p. 101625, 2023, doi: 10.1016/j.uclim.2023.101625.

[49] J. Lewtas, "Air pollution combustion emissions: characterization of causative agents and mechanisms associated with cancer, reproductive, and cardiovascular effects," *Mutation Research/Reviews in Mutation Research*, vol. 636, no. 1–3, pp. 95–133, 2007, doi: 10.1016/j.mrrev.2007.08.003.

[50] A. Charron, R. M. Harrison, and P. Quincey, "What are the sources and conditions responsible for exceedences of the 24 h PM10 limit value (50 μg m− 3) at a heavily trafficked London site?," *Atmospheric Environment*, vol. 41, no. 9, pp. 1960–1975, 2007, doi: 10.1016/j.atmosenv.2006.10.041.

[51] A. Thorpe and R. M. Harrison, "Sources and properties of non-exhaust particulate matter from road traffic: a review," *Science of the total environment*, vol. 400, no. 1–3, pp. 270–282, 2008, doi: 10.1016/j.scitotenv.2008.06.007.

[52] A. B. D. Nandiyanto *et al.*, "The effects of rice husk particles size as a reinforcement component on resin-based brake pad performance: From literature review on the use of agricultural waste as a reinforcement material, chemical polymerization reaction of epoxy resin, to experiments," *Automotive Experiences*, vol. 4, no. 2, pp. 68–82, 2021, doi:

10.31603/ae.5217.

[53] A. B. D. Nandiyanto, R. Ragadhita, M. Fiandini, D. F. Al Husaeni, D. N. Al Husaeni, and F. Fadhillah, "Domestic waste (eggshells and banana peels particles) as sustainable and renewable resources for improving resin-based brakepad performance: Bibliometric literature review, techno-economic analysis, dual-sized reinforcing experiments, to comparison...," *Communications in Science and Technology*, vol. 7, no. 1, pp. 50–61, 2022, doi: 10.21924/cst.7.1.2022.757.

[54] O. R. Adetunji, A. M. Adedayo, S. O. Ismailia, O. U. Dairo, I. K. Okediran, and O. M. Adesusi, "Effect of silica on the mechanical properties of palm kernel shell based automotive brake pad," *Mechanical Engineering for Society and Industry*, vol. 2, no. 1, pp. 7–16, 2022, doi: 10.31603/mesi.6178.

[55] G. Akıncıoğlu, S. Akıncıoğlu, H. Öktem, and İ. Uygur, "Wear response of non-asbestos brake pad composites reinforced with walnut shell dust," *Journal of the Australian Ceramic Society*, vol. 56, pp. 1061–1072, 2020, doi: 10.1007/s41779-020-00452-6.

[56] S. Choosri, N. Sombatsompop, E. Wimolmala, and S. Thongsang, "Potential use of fly ash and bagasse ash as secondary abrasives in phenolic composites for eco-friendly brake pads applications," *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, vol. 233, no. 5, pp. 1296–1305, 2019, doi: 10.1177/0954407018772240.

[57] C. H. Achebe, E. N. Obika, J. L. Chukwuneke, and O. E. Ani, "Optimisation of hybridised cane wood–palm fruit fibre frictional material," *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, vol. 233, no. 12, pp. 2490–2497, 2019, doi: 10.1177/1464420719863445.

[58] N. H. A. Norhasnan *et al.*, "Physicomechanical properties of rice husk/coco peat reinforced acrylonitrile butadiene styrene blend composites," *Polymers*, vol. 13, no. 7, p. 1171, 2021, doi: 10.3390/polym13071171.

[59] I. O. Adeyemi, A. A. Nuhu, and E. B. Thankgod, "Development of asbestos-free automotive brake pad using ternary agro-waste fillers," *Development*, vol. 3, no. 7, pp. 5307–5323, 2016.

[60] O. A. Ajibade, J. O. Agunsoye, and S. A. Oke, "A wear rate model incorporating inflationary cost of agro-waste filled composites for brake pad applications to lower composite cost," *SN Applied Sciences*, vol. 3, pp. 1–21, 2021, doi: 10.1007/s42452-020-04016-y.

[61] A. I. Olabisi, A. N. Adam, and O. M. Okechukwu, "Development and assessment of composite brake pad using pulverized cocoa beans shells filler," *International Journal of Materials Science and Applications*, vol. 5, no. 2, pp. 66–78, 2016, doi: 10.11648/j.ijmsa.20160502.16.

[62] D. Chan and G. W. Stachowiak, "Review of automotive brake friction materials," *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, vol. 218, no. 9, pp. 953–966, 2004, doi: 10.1243/0954407041856773.

[63] B. D. Garg, S. H. Cadle, P. A. Mulawa, P. J. Groblicki, C. Laroo, and G. A. Parr, "Brake wear particulate matter emissions," *Environmental Science & Technology*, vol. 34, no. 21, pp. 4463–4469, 2000, doi: 10.1021/es001108h.

[64] P. G. Sanders, N. Xu, T. M. Dalka, and M. M. Maricq, "Airborne brake wear debris: size distributions, composition, and a comparison of dynamometer and vehicle tests," *Environmental science & technology*, vol. 37, no. 18, pp. 4060–4069, 2003, doi: 10.1021/es034145s.

[65] N. N. Azizah, R. Maryanti, and A. B. D. Nandiyanto, "How to search and manage references with a specific referencing style using google scholar: From step-by-step processing for users to the practical examples in the referencing education," *Indonesian Journal of Multidiciplinary Research*, vol. 1, no. 2, pp. 267–294, 2021, doi: 10.17509/ijomr.v1i2.37694.

[66] A. B. D. Nandiyanto, M. K. Biddinika, and F. Triawan, "Evaluation on research effectiveness in a subject area among top class universities: a case of Indonesia's academic publication dataset on chemical and material sciences," *Journal of Engineering*

Science and Technology, vol. 15, no. 3, pp. 1747–1775, 2020.

[67] A. B. D. Nandiyanto, M. K. Biddinika, and F. Triawan, "How bibliographic dataset portrays decreasing number of scientific publication from Indonesia," *Indonesian Journal of Science and Technology*, vol. 5, no. 1, pp. 154–175, 2020, doi: 10.17509/ijost.v5i1.22265.

[68] J. Kelly, T. Sadeghieh, and K. Adeli, "Peer review in scientific publications: benefits, critiques, & a survival guide," *Ejifcc*, vol. 25, no. 3, p. 227, 2014.

[69] X. Cao, Y. Chen, and K. J. R. Liu, "A data analytic approach to quantifying scientific impact," *Journal of Informetrics*, vol. 10, no. 2, pp. 471–484, 2016, doi: 10.1016/j.joi.2016.02.006.

[70] A. Agarwal *et al.*, "Bibliometrics: tracking research impact by selecting the appropriate metrics," *Asian journal of andrology*, vol. 18, no. 2, p. 296, 2016, doi: 10.4103/1008-682X.171582.

[71] E. Roldan-Valadez, S. Y. Salazar-Ruiz, R. Ibarra-Contreras, and C. Rios, "Current concepts on bibliometrics: a brief review about impact factor, Eigenfactor score, CiteScore, SCImago Journal Rank, Source-Normalised Impact per Paper, H-index, and alternative metrics," *Irish Journal of Medical Science (1971-)*, vol. 188, pp. 939–951, 2019, doi: 10.1007/s11845-018-1936-5.

[72] K. Balakrishnan *et al.*, "The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: the Global Burden of Disease Study 2017," *The Lancet Planetary Health*, vol. 3, no. 1, pp. e26–e39, 2019, doi: 10.1016/S2542-5196(18)30261-4.

[73] R. J. Farrauto, M. Deeba, and S. Alerasool, "Gasoline automobile catalysis and its historical journey to cleaner air," *Nature Catalysis*, vol. 2, no. 7, pp. 603–613, 2019, doi: 10.1038/s41929-019-0312-9.

[74] A. B. D. Nandiyanto, D. N. Al Husaeni, and D. F. Al Husaeni, "Introducing ASEAN Journal of Science and Engineering: A Bibliometric Analysis Study," *Journal of Advanced Research in Applied Sciences and Engineering Technology*, vol. 31, no. 3, pp. 173–190, 2023, doi: 10.37934/araset.31.3.173190.

[75] D. N. Al Husaeni, D. F. Al Husaeni, A. B. D. Nandiyanto, and A. S. M. Al-Obaidi, "Introducing ASEAN Journal of Science and Engineering Education: A bibliometric analysis study for understanding internationalization," *Data and Metadata*, vol. 1, p. 43, 2022, doi: 10.56294/dm202282.

[76] A. B. D. Nandiyanto, D. N. Al Husaeni, D. F. Al Husaeni, I. Hamidah, B. Maftuh, and M. Solehuddin, "Is Universitas Pendidikan Indonesia Ready for Internationalization? A Bibliometric Analysis in The Science and Technology-Related Publications," *Journal of Advanced Research in Applied Sciences and Engineering Technology*, vol. 32, no. 2, pp. 14–29, 2023, doi: 10.37934/araset.32.2.1429.

[77] A. B. D. Nandiyanto, R. Ragadhita, and M. Aziz, "Involving Particle Technology in Computational Fluid Dynamics Research: A Bibliometric Analysis," *CFD Letters*, vol. 15, no. 11, pp. 92–109, 2023, doi: 10.37934/cfdl.15.11.92109.

[78] D. F. Al Husaeni *et al.*, "How technology can change educational research? Definition, factors for improving quality of education and computational bibliometric analysis," *ASEAN Journal of Science and Engineering*, vol. 4, no. 2, pp. 127–166, 2024, doi: 10.17509/ajse.v4i2.62045.

[79] K. Meehan, N. L. Klenk, and F. Mendez, "The geopolitics of climate knowledge mobilization: Transdisciplinary research at the science–policy interface (s) in the Americas," *Science, Technology, & Human Values*, vol. 43, no. 5, pp. 759–784, 2018, doi: 10.1177/0162243917745601.

[80] X. Wang *et al.*, "Influence of coal co-firing on the particulate matter formation during pulverized biomass combustion," *Journal of the Energy Institute*, vol. 92, no. 3, pp. 450–458, 2019, doi: 10.1016/j.joei.2018.05.003.

[81] I. Veza *et al.*, "Strategies to achieve controlled auto-ignition (CAI) combustion: A review," *Mechanical Engineering for Society and Industry*, vol. 3, no. 1, pp. 22–34, 2023, doi: 10.31603/mesi.7568.

[82] A. Kolakoti, A. V. Kumar, R. Metta, M. Setiyo, and M. L. Rochman, "Experimental studies on in-cylinder combustion, exergy performance, and exhaust emission in a Compression Ignition engine fuelled with

neat biodiesels," *Indonesian Journal of Science and Technology*, vol. 7, no. 2, pp. 219–236, 2022, doi: 10.17509/ijost.v7i2.49680.

[83] B. O. Bolaji, D. O. Bolaji, and S. T. Amosun, "Energy and cooling performance of carbon-dioxide and hydrofluoroolefins blends as eco-friendly substitutes for R410A in air-conditioning systems," *Mechanical Engineering for Society and Industry*, vol. 3, no. 1, pp. 35–46, 2023, doi: 10.31603/mesi.8591.

[84] M. A. Ramly and M. Setiyo, "Carbon black: Production, properties, and utilization," *Mechanical Engineering for Society and Industry*, vol. 3, no. 1, pp. 1–3, 2023, doi: 10.31603/mesi.8821.

[85] M. Setiyo, "Alternative fuels for transportation sector in Indonesia," *Mechanical Engineering for Society and Industry*, vol. 2, no. 1, pp. 1–6, 2022, doi: 10.31603/mesi.6850.

[86] L. M. Olalekan, O. Olatunde, F. I. Olufemi, and A. A. Olamide, "Mathematical modeling and cost comparison for electricity generation from petrol and liquified petroleum gas (LPG)," *Mechanical Engineering for Society and Industry*, vol. 2, no. 2, pp. 57–63, 2022, doi: 10.31603/mesi.6697.

[87] S. Munahar, B. C. Purnomo, and H. Köten, "Fuel control systems for planetary transmission vehicles: A contribution to the LPG-fueled vehicles community," *Mechanical Engineering for Society and Industry*, vol. 1, no. 1, pp. 14–21, 2021, doi: 10.31603/mesi.5263.

[88] M. Setiyo, N. Widodo, B. C. Purnomo, S. Munahar, M. A. Rahmawan, and A. Luthfi, "Harvesting cooling effect on lpg-fueled vehicles for mini cooler: A lab-scale investigation," *Indonesian Journal of Science and Technology*, vol. 4, no. 1, pp. 39–47, 2019, doi: 10.17509/ijost.v4i1.12834.

[89] A. Kolakoti, M. Setiyo, and B. Waluyo, "Biodiesel production from waste cooking oil: Characterization, modeling and optimization," *Mechanical Engineering for Society and Industry*, vol. 1, no. 1, pp. 22–30, 2021, doi: 10.31603/mesi.5320.

[90] A. Bhikuning and J. S. Senda, "The properties of fuel and characterization of functional groups in biodiesel-water emulsions from waste cooking oil and its blends," *Indonesian Journal of Science and Technology*, vol. 5, no. 1, pp. 95–108, 2020, doi: 10.17509/ijost.v5i1.23103.

[91] A. Hidayat, W. Kurniawan, and H. Hinode, "Sugarcane bagasse biochar as a solid catalyst: From literature review of heterogeneous catalysts for esterifications to the experiments for biodiesel synthesis from palm oil industry waste residue," *Indonesian Journal of Science and Technology*, vol. 6, no. 2, pp. 337–352, 2021, doi: 10.17509/ijost.v6i2.34498.

[92] K. Kareem, M. Rasheed, A. Liaquat, A. M. M. Hassan, M. I. Javed, and M. Asif, "Clean energy production from jatropha plant as renewable energy source of biodiesel," *ASEAN Journal of Science and Engineering*, vol. 2, no. 2, pp. 193–198, 2022, doi: 10.17509/ajse.v2i2.39163.

[93] J. D. Waghmare, S. S. Patil, S. M. Patil, and M. Maske, "Study and review of properties and applications of Portland Pozzolana cement," *ASEAN Journal of Science and Engineering*, vol. 1, no. 1, pp. 13–18, 2021, doi: 10.17509/ajse.v1i1.37980.

[94] F. B. Elehinafe, S. N. Ezekiel, O. B. Okedere, and O. O. Odunlami, "Cement industry–Associated emissions, environmental issues and measures for the control of the emissions," *Mechanical Engineering for Society and Industry*, vol. 2, no. 1, pp. 17–25, 2022, doi: 10.31603/mesi.5622.

[95] S. N. Sutar, P. V. Patil, R. V. Chavan, and M. M. Maske, "Study and review of ordinary Portland cement," *ASEAN Journal of Science and Engineering*, vol. 1, no. 3, pp. 153–160, 2021, doi: 10.17509/ajse.v1i3.37973.