

Waste-to-Energy: A Bibliometric Analysis

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Article Info	ABSTRACT
<i>Article history:</i> Received Sep, 2026 Revised Sep, 2026 Accepted Sep, 2026 <i>Keywords:</i> Bibliometric Analysis Circular Economy VOSviewer Waste Incineration Waste-to-Energy	This study presents a bibliometric analysis of waste-to-energy (WtE) research to map its intellectual structure, thematic evolution, influential works, and collaboration patterns. A total of 2,513 Scopus-indexed documents published between 2000 and 2026 were retrieved and analyzed with VOSviewer through keyword co-occurrence (network, overlay, and density visualizations), citation analysis, and co-authorship analysis at the author, institution, and country levels. The keyword network reveals five interconnected clusters: thermal conversion and plant energy performance, waste management systems and incineration residues, bioenergy and circular economy, technology selection and decision making, and life cycle and climate impacts. The overlay map shows a shift from boiler, heat recovery, and disposal-oriented studies toward renewable energy, anaerobic digestion, circular economy, life cycle assessment, and decision-support research, while the density map confirms that incineration-based WtE and waste management remain the dominant research core. The most cited documents are reviews on municipal solid waste management, circular economy, incineration, and food waste bioconversion. Co-authorship networks are organized into several cohesive but weakly connected groups, with Themelis as the most prominent author, and the United States, China, and India acting as the main country hubs, alongside a visible contribution from Indonesia and other emerging economies. The findings indicate a transition of WtE research from plant-level engineering toward integrated, sustainability-oriented, and policy-relevant investigations. <i>This is an open access article under the CC BY-SA license.</i> 
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1. INTRODUCTION

The rapid growth of urban populations, industrial activity, and consumption has increased the generation of municipal solid waste (MSW) worldwide, while space for sanitary landfills is becoming scarce and landfilling continues to release methane, leachate, and other environmental

burdens. Waste-to-energy (WtE) has emerged as a strategy that addresses both problems at once by converting non-recyclable residual waste into electricity, heat, or fuels, thereby reducing waste volume and substituting part of fossil-based energy supply [1], [2]. In many developed economies, WtE is no longer viewed merely as a disposal option but as a component of integrated waste management

that complements recycling within the circular economy and energy recycling agenda [3].

WtE covers a broad portfolio of technologies. Mass-burn incineration with energy recovery remains the most mature and widely deployed route, and its evolution has been driven by improvements in combustion control, flue gas cleaning, and energy efficiency [4]. Advanced thermochemical options such as gasification, co-gasification, and pyrolysis offer higher flexibility in producing syngas, oils, and chars [5], whereas biochemical routes, particularly anaerobic digestion, are preferred for wet organic fractions such as food waste [6], [7].

Despite these advantages, WtE remains contested because its environmental and economic performance depends strongly on waste composition, technology choice, and local energy systems. Life cycle assessment (LCA) studies show that the net benefits of WtE vary with energy substitution assumptions and residue management [8]. Economic analyses highlight high capital costs, tipping-fee dependence, and investment risks [9], while other studies emphasize supply chain design and the complementary role of WtE in circular economy systems and as an alternative to landfilling [10].

The relevance of WtE is particularly strong in developing and emerging economies, where waste generation is growing rapidly and landfills are often poorly managed. Reviews have examined technological options for MSW in such contexts [11], and country-level assessments have been conducted for Saudi Arabia and Indonesia [12], [13]. However, these countries still face barriers related to high-moisture waste, limited financing, weak institutions, and low public acceptance, which require context-specific policies [14].

The expansion of WtE research across engineering, environmental science, energy, and policy disciplines has produced a large and fragmented body of literature. Previous bibliometric studies have examined specific segments of this field, such as incineration research between 1999 and 2015 [15], WtE in

the circular economy [16], carbon-neutral perspectives [17], and sustainability models for waste power plants in Indonesia [18]. These studies are either limited in time span or focused on particular subtopics, and an updated and integrated mapping that covers recent publications up to 2026 is still lacking. Therefore, this study aims to (1) identify the main thematic clusters of WtE research, (2) trace its thematic evolution and research hotspots, (3) identify the most influential documents, and (4) map collaboration patterns among authors, institutions, and countries.

2. METHODS

This study employed a bibliometric approach to analyze the scientific development of WtE research. Bibliographic data were retrieved from the Scopus database because of its broad coverage of peer-reviewed literature in engineering, energy, and environmental sciences, and because it has been widely used in previous bibliometric studies on WtE topics [19]. The search targeted documents containing the term “waste-to-energy” and its spelling variant “waste to energy” in the article title, without restriction on publication year, and the data were exported on 14 September 2026. The final dataset comprised 2,513 documents published between 2000 and 2026, consisting of 1,423 articles, 520 conference papers, 262 book chapters, 211 reviews, and a small number of other document types. The complete records, including titles, abstracts, author keywords, index keywords, author names, affiliations, source titles, publication years, and citation counts, were exported in RIS format.

Bibliometric mapping was conducted using VOSviewer, a tool that has been applied in previous WtE science mapping studies to visualize performance indicators, keyword evolution, and collaboration networks [20]. Keyword co-occurrence analysis was performed on all keywords and presented as network, overlay, and density visualizations to identify thematic clusters, temporal evolution, and research hotspots. Citation

analysis was used to identify the ten most cited documents based on Scopus citation counts. Co-authorship analysis was carried out at the author, institution, and country levels to reveal collaboration structures, key contributors, and bridging actors in the field.

3. RESULTS AND DISCUSSION

3.1 Keyword Co-Occurrence Network Visualization

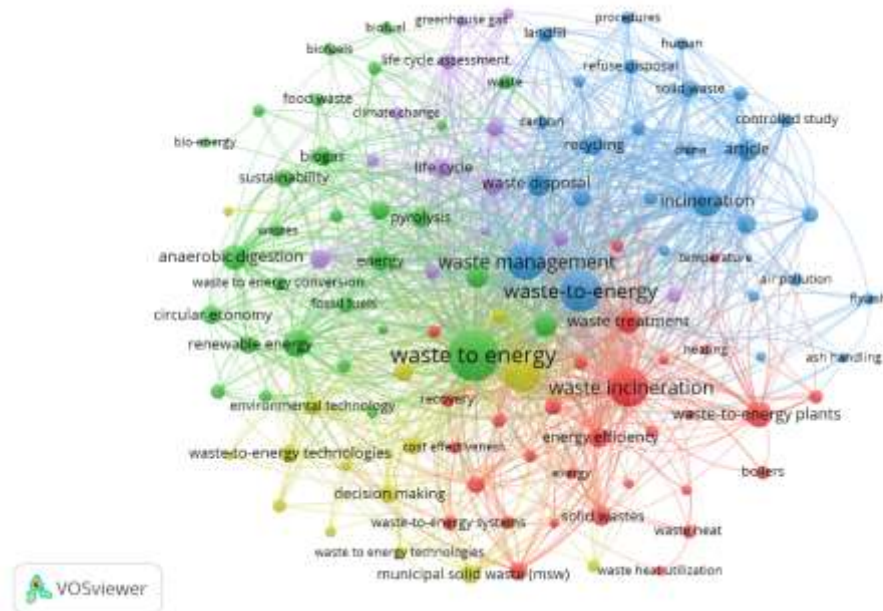


Figure 1. Network Visualization

Source: Data Analysis, 2026

Figure 1 shows that the intellectual structure of WtE research is centered on the terms “waste to energy”, “waste-to-energy”, “waste management”, and “waste incineration”, which are the largest and most connected nodes. The coexistence of hyphenated and non-hyphenated forms of the same concept, together with their dense linkages, indicates that WtE functions as the unifying concept connecting engineering, environmental, and management themes. The network is organized into five clusters.

The red cluster represents the thermal conversion and energy performance of WtE plants. It includes waste incineration, waste-to-energy plants, energy efficiency, exergy, boilers, heating, temperature, waste heat, waste heat utilization, solid wastes, and waste-to-energy systems. This cluster reflects research on plant design and operation, such as high-temperature corrosion in boilers [21], waste heat recovery, and energy and exergy

analyses of WtE plants. The blue cluster reflects the waste management system and its environmental burdens, with keywords such as incineration, recycling, landfill, refuse disposal, waste disposal, solid waste, carbon, air pollution, fly ash, and ash handling. It covers the management of incineration residues [22] and the deployment and emissions of WtE facilities, particularly in China [23].

The green cluster is associated with bioenergy and the circular economy, including anaerobic digestion, biogas, pyrolysis, food waste, biofuels, bio-energy, renewable energy, fossil fuels, sustainability, and circular economy. It highlights the positioning of WtE as a renewable energy source and a resource recovery pathway, especially for organic waste [24]. The yellow cluster focuses on technology selection and evaluation, with waste-to-energy technologies, decision making, cost

effectiveness, environmental technology, and municipal solid waste (msw), reflecting the growing use of multi-criteria decision tools to select appropriate WtE options [25]. The purple cluster, consisting of life cycle assessment, life cycle, greenhouse gas, and climate change, represents research that evaluates the environmental and climate performance of WtE systems [26]. Overall, the strong interconnections among clusters show that WtE is a highly interdisciplinary field in which technical, environmental, and decision-making perspectives are closely integrated.

In terms of node size, waste to energy, waste-to-energy, waste management, and

waste incineration are followed by incineration, waste treatment, renewable energy, anaerobic digestion, and energy efficiency, showing that the field is built around both thermal and biological conversion routes. Keywords such as waste treatment, recovery, energy, and municipal solid waste (msw) are located between clusters and act as bridging concepts that connect plant engineering, waste management, and sustainability themes. This structure indicates that WtE research treats MSW simultaneously as a waste management problem and an energy resource.

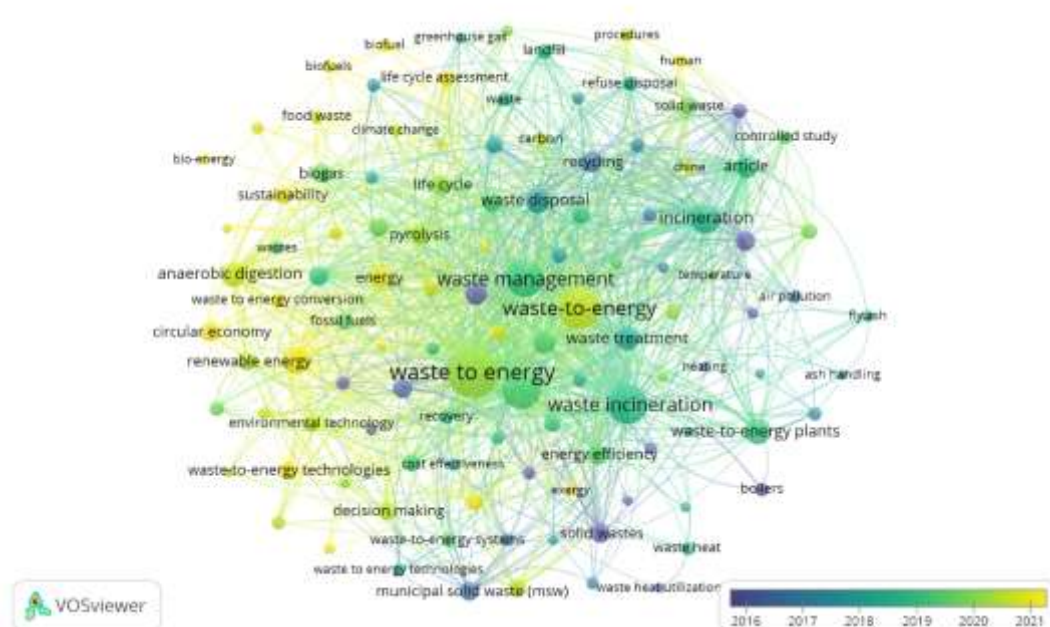


Figure 2. Overlay Visualization

Source: Data Analysis, 2026

Figure 2 presents the temporal evolution of WtE research, with colors indicating the average publication year of each keyword from 2016 (purple) to 2021 (yellow). Older themes are dominated by solid wastes, boilers, heating, recycling, waste disposal, and municipal solid waste (msw), indicating that early research focused on combustion engineering and disposal-oriented waste management. Keywords in teal and green, such as waste incineration, incineration, waste management, waste treatment, landfill, fly ash, refuse disposal,

cost effectiveness, and waste-to-energy plants, represent the consolidated core of the field that developed around 2018–2019.

The most recent themes, shown in yellow, include waste-to-energy, renewable energy, circular economy, anaerobic digestion, sustainability, biofuels, food waste, climate change, life cycle assessment, decision making, and waste-to-energy technologies. This pattern indicates a shift from plant-level engineering toward sustainability-oriented, system-level, and policy-relevant research. The recent attention to circular economy and

climate issues is consistent with emerging studies linking WtE to hydrogen production and resource recovery [27], as well as to the decarbonization of WtE plants through carbon capture, utilization, and storage [28].

The overlay map also shows that keywords such as china, human, procedures, and controlled study appear in yellow-green, reflecting the recent increase in country-based

case studies and assessments of health and emission impacts around WtE facilities. This thematic shift coincides with the rapid growth of publications, from 151 documents in 2020 to 275 documents in 2024, indicating that newer research agendas are expanding the field rather than replacing its engineering foundation

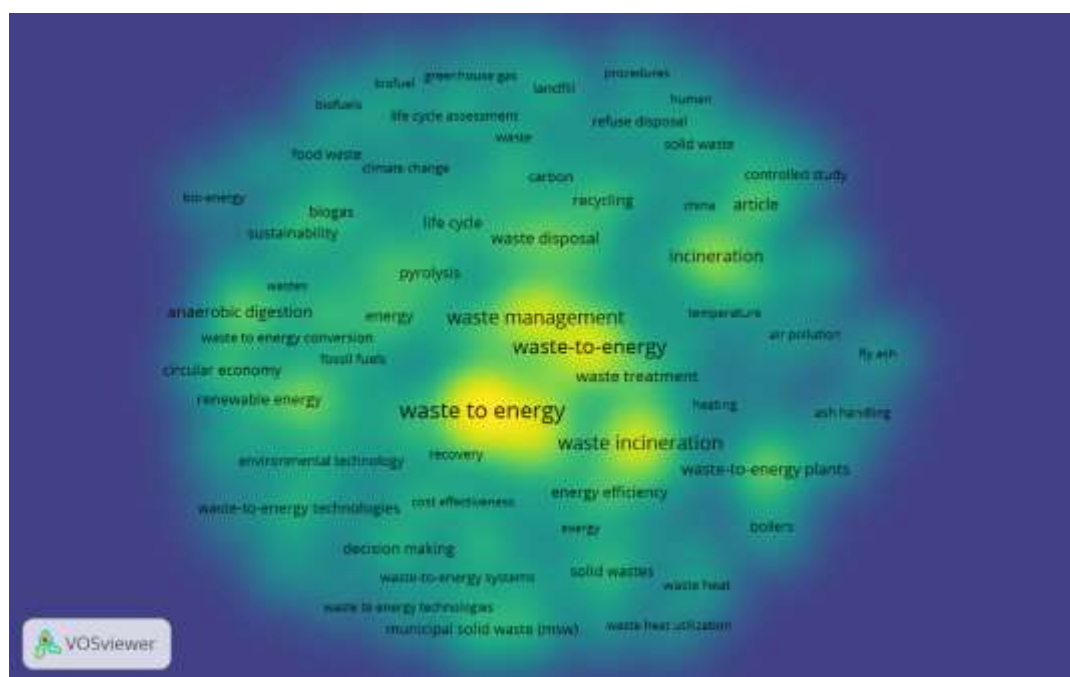


Figure 3. Density Visualization

Source: Data Analysis, 2026

Figure 3 shows that research intensity is highly concentrated around “waste to energy”, “waste-to-energy”, “waste management”, and “waste incineration”, which form the brightest areas of the map. Secondary hotspots are located around incineration, waste-to-energy plants, waste treatment, renewable energy, and anaerobic digestion, confirming that incineration-based energy recovery and its integration into waste management systems remain the dominant research core.

In contrast, the peripheral areas with lower density include bio-energy, biofuels, food waste, climate change, fly ash, ash handling, boilers, waste heat utilization, and decision making. These topics are either specialized engineering niches or relatively new themes that have not yet reached the

same level of maturity. Combined with the overlay results, the low density of recent keywords such as circular economy, life cycle assessment, and decision making suggests promising opportunities for future research on sustainability assessment, residue valorization, and the selection of context-appropriate WtE technologies.

The density pattern also mirrors the cluster structure in Figure 1. The lower-right region, dominated by waste incineration and waste-to-energy plants, forms a clear hotspot for thermal WtE research, while the left region around renewable energy, anaerobic digestion, and circular economy shows moderate density, reflecting an active but still developing bioenergy stream. The upper region containing life cycle assessment, greenhouse gas, and landfill remains

relatively cool, suggesting that environmental assessment studies are dispersed across many specific topics rather than concentrated in a single dominant theme.

3.2 Citation Analysis

Table 1. Top Cited Documents

Citations	Authors and Year	Title
829	[3]	Municipal solid waste management and waste-to-energy in the context of a circular economy and energy recycling in Europe
787	[11]	A review on technological options of waste to energy for effective management of municipal solid waste
649	[6]	Bioconversion of food waste to energy: A review
642	[7]	Food waste-to-energy conversion technologies: Current status and future directions
568	[10]	Strategies on implementation of waste-to-energy (WTE) supply chain for circular economy system: a review
545	[2]	Waste to energy - key element for sustainable waste management
528	[4]	The evolution of waste-to-energy incineration: A review
496	[24]	Food Waste to Energy: An Overview of Sustainable Approaches for Food Waste Management and Nutrient Recycling
441	[12]	Waste to energy potential: A case study of Saudi Arabia
439	[1]	Waste-to-energy: A way from renewable energy sources to sustainable development

Source: Scopus, 2026

3.3 Co-Authorship Analysis

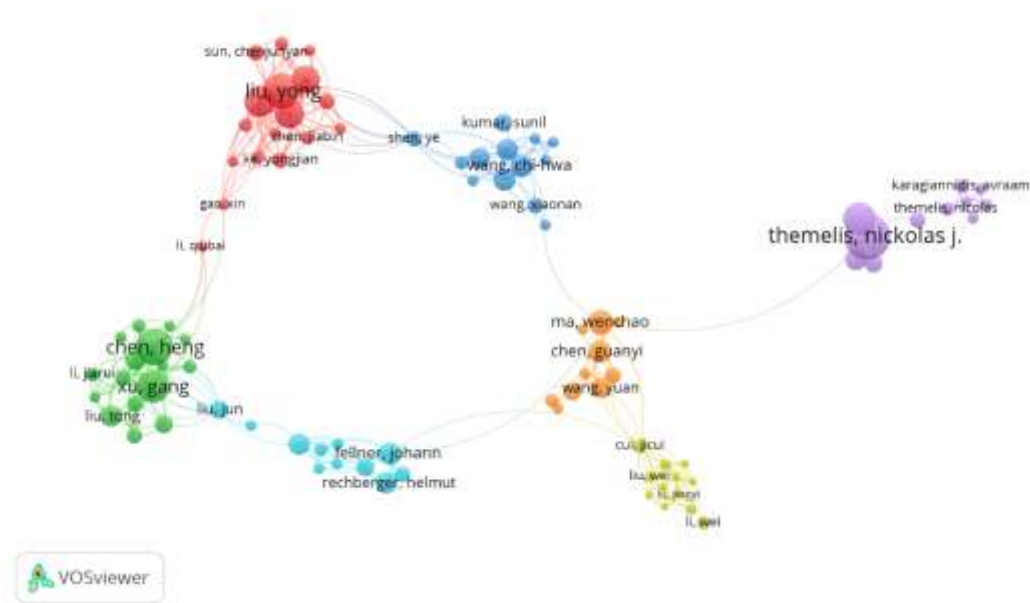


Figure 4. Author Visualization
Source: Data Analysis, 2026

Figure 4 reveals a ring-shaped co-authorship structure consisting of seven relatively cohesive clusters that are connected by only a few bridging authors. The largest

node belongs to Themelis, Nickolas J., who is also the most productive author in the dataset. His purple cluster, which includes Karagiannidis, Avraam, represents a long-standing research line on WtE status, boiler corrosion, and the global expansion of WtE capacity [29], as well as WtE planning in Greece. The appearance of “Themelis, Nicolas” as a separate node indicates an author name variant that should be considered when interpreting productivity.

The red cluster (Liu, Yong; Sun, Chenjunyan; Chen, Jiabin; Ke, Yongjian; Gao, Xin; and Li, Qiubai) is associated with public acceptance and governance of WtE incineration projects in China [30]. The blue cluster (Wang, Chi-Hwa; Kumar, Sunil; Shen, Ye; and Wang, Xiaonan) focuses on food waste valorization, including life cycle comparisons of food waste WtE scenarios and hybrid biological–thermal WtE systems with heat recovery, while the green cluster (Chen, Heng; Xu, Gang; Li, Jiarui; and Liu, Tong) works on the integration of WtE with power plants. The cyan cluster (Fellner, Johann; Rechberger, Helmut; and Liu, Jun) addresses

carbon accounting and the biogenic share of WtE electricity, whereas the orange (Ma, Wenchao; Chen, Guanyi; and Wang, Yuan) and yellow (Cui, Jicui; Liu, Wei; Lu, Jingyi; and Li, Wei) clusters focus on combustion and air pollutant emissions of WtE plants. Authors such as Shen, Ye, Liu, Jun, and Ma, Wenchao act as bridges between clusters, indicating that knowledge exchange across research groups depends on a small number of connectors.

The distribution of the clusters also indicates that most collaboration groups are formed along national or institutional lines, with Chinese research groups forming the majority of the clusters and European and American groups forming smaller but highly cited communities. The weak links between clusters suggest that thematic streams such as social acceptance, plant integration, emission control, and carbon accounting are developed by separate groups, so stronger cross-group collaboration could accelerate the integration of technical, environmental, and social dimensions of WtE research.

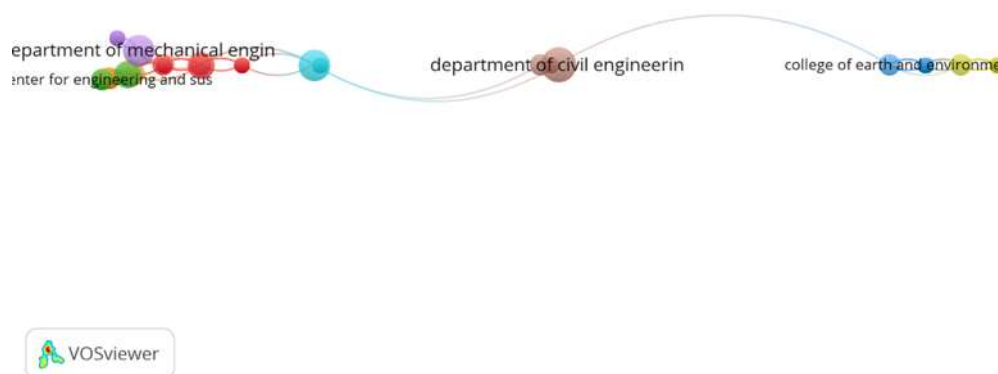


Figure 5. Institution Visualization

Source: Data Analysis, 2026

Figure 5 shows a sparse and chain-like institutional collaboration network. On

the left side, a group of institutions dominated by departments of mechanical engineering

and the Center for Engineering and Sustainable Development Research is densely linked internally. The Department of Civil Engineering in the middle acts as the main broker, connecting this group with a small cluster on the right that includes the College of Earth and Environmental Sciences. The limited number of links suggests that institutional collaboration in WtE research remains fragmented and is largely confined to a few department-level partnerships. The frequent appearance of generic department names also indicates that affiliation data are recorded at the sub-institutional level, so the map mainly reflects collaboration among

specific research units rather than entire universities.

The disciplinary composition of the connected institutions, namely mechanical engineering, civil engineering, and earth and environmental sciences, reflects the multidisciplinary nature of WtE research, in which energy conversion, infrastructure, and environmental impacts must be addressed together. However, the small number of connected nodes indicates that only a limited set of institutions meets the collaboration threshold, confirming that institutional partnerships in this field are still weak compared with the dense keyword and country networks.

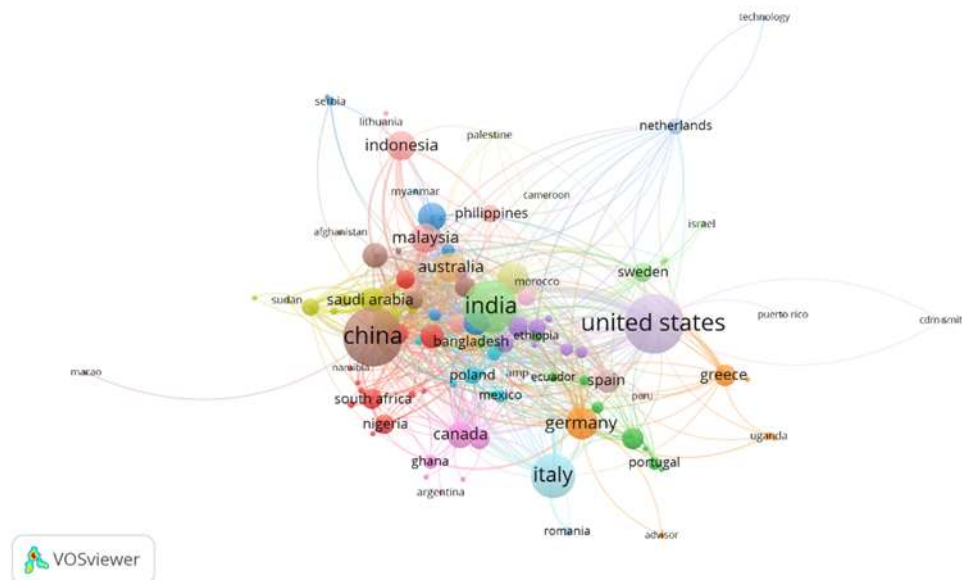


Figure 6. Country Visualization

Source: Data Analysis, 2026

Figure 6 shows that the United States, China, and India are the main hubs of WtE research, as indicated by their large node sizes and extensive links. The United States has a long tradition of WtE research, China has become a major contributor following the rapid expansion of its incineration industry, and India has produced a large body of work on MSW-based WtE potential. Italy, Germany, Greece, Spain, Poland, Sweden, the Netherlands, and Portugal form a strong European group, while Canada and Australia maintain broad international connections.

Asian emerging economies, including Indonesia, Malaysia, the Philippines, Bangladesh, and Saudi Arabia, form a visible and densely connected group, reflecting growing interest in WtE as a solution to rapid urbanization and landfill pressure. African countries such as South Africa, Nigeria, Ghana, Ethiopia, and Morocco, as well as smaller contributors such as Serbia, Lithuania, Romania, Sudan, Myanmar, and Uganda, appear more peripheral, indicating limited research capacity and collaboration. Several nodes such as “technology”, “advisor”, “cdm

smith", and "amp" are artifacts of affiliation parsing rather than countries and should be interpreted with caution.

The country network indicates that knowledge production is concentrated in a few leading countries, while developing economies where WtE deployment is most urgent still depend on international partnerships [14]. For countries such as Indonesia, the strong position in the Asian group suggests growing research capacity that can support national WtE programs, particularly those that combine incineration for residual waste with biochemical routes for high-organic waste [13], [18].

4. CONCLUSION

This bibliometric analysis of 2,513 Scopus-indexed documents shows that waste-to-energy research has developed into a mature, rapidly growing, and highly interdisciplinary field. The keyword network is organized into five clusters covering thermal conversion and plant performance,

waste management systems and residues, bioenergy and circular economy, technology selection and decision making, and life cycle and climate impacts. The overlay and density maps indicate that incineration-based energy recovery remains the research core, while recent attention has shifted toward renewable energy, anaerobic digestion, circular economy, life cycle assessment, and decision-support approaches. The most influential works are reviews on MSW management, circular economy, incineration, and food waste conversion. Collaboration networks are formed by several cohesive but weakly connected groups, with the United States, China, and India as the main hubs and emerging economies such as Indonesia showing increasing participation. Future research should strengthen integrated sustainability assessment, residue valorization, decarbonization of WtE plants, and international collaboration that supports context-appropriate WtE deployment in developing countries.

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