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Evidence-Based Integrated Waste Management Framework for Adiwiyata Schools: A Systematic Review and Bibliometric Mapping

Asiah[1], Ahmad Nubli Gadeng[2], and Ichwana Ramli[3]

[1] Master Program of Environmental Management, Graduate School, Universitas Syiah Kuala, Indonesia
[2] Geography Education Study Program, Graduate School, Universitas Syiah Kuala, Indonesia
[3] Master Program of Environmental Management, Graduate School, Universitas Syiah Kuala, Indonesia

*ahmadnubli@usk.ac.id

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ABSTRACT

Waste management has become an increasingly significant global challenge, requiring sustainable approaches such as waste-to-energy (WtE), which can reduce waste volume while generating alternative energy. However, existing waste management studies are still dominated by technical perspectives and have not sufficiently integrated educational dimensions within school environments. This study aims to analyze the development of literature related to school-based waste management using a waste-to-energy approach and to develop an integrated waste management model for Adiwiyata schools. The study employed a systematic literature review (SLR) based on PRISMA 2020 guidelines combined with bibliometric analysis using VOSviewer. Data were collected from Scopus publications from 2006–2025, resulting in 133 articles selected for analysis. The findings indicate a significant increase in publications since 2016, accompanied by a paradigm shift from waste disposal toward resource recovery and circular economy approaches. This study proposes a quadruple system model consisting of institutional, operational, financial, and evaluative dimensions integrated with an educational dimension as a hidden curriculum. The proposed model is expected to support sustainable waste management and strengthen environmental education implementation in Adiwiyata schools.

Keywords: adiwiyata school, bibliometric analysis, enviromental education, waste management, waste-to-energy

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INTRODUCTION

Waste management has become an increasingly complex global challenge, particularly in developing countries experiencing rapid increases in waste generation due to population growth, urbanization, and changing consumption patterns. Globally, waste volume is projected to increase from 2.01 billion tons in 2016 to 3.40 billion tons by 2050, with most of the increase occurring in low- and middle-income countries (Kaza et al., 2018). This condition places significant pressure on waste management systems, contributing to environmental pollution and greenhouse gas emissions. In response to these challenges, the waste-to-energy (WtE) approach has emerged as a strategic solution in modern waste management. This technology enables the conversion of waste into energy through thermal and biological processes such as incineration, gasification, and anaerobic digestion. Previous studies have shown that WtE implementation can reduce waste volume by up to 70–90% while generating alternative energy that contributes to resource efficiency (Alao et al., 2022). Furthermore, the increasing use of renewable energy derived from waste has been proven to significantly reduce long-term CO_2 emissions, particularly in developing countries (Raihan et al., 2022).

This study is grounded in five key concepts: integrated sustainable waste management, waste-to-energy, Adiwiyata, hidden curriculum, and circular economy. Integrated sustainable waste management refers to a systemic approach that combines technical, institutional, financial, social, and environmental aspects to reduce waste and improve resource recovery (Marshall & Farahbakhsh, 2013; Guerrero et al., 2013). Waste-to-energy refers to the recovery of energy from waste through appropriate technologies. However, in the school context, WtE should be positioned as an educational and partnership-based concept rather than the direct operation of high-risk technologies such as incineration. Adiwiyata is an Indonesian environmental education program that encourages schools to develop environmentally responsible policies, curriculum implementation, participatory activities, and supporting facilities. In this context, waste management becomes part of school culture and contextual learning.

The hidden curriculum refers to values and behaviors learned indirectly through school routines and practices, such as waste sorting, composting, recycling, and environmental projects (Jackson, 1968; Ardoin et al., 2020). Meanwhile, the circular economy emphasizes waste reduction, reuse, recycling, and resource recovery, shifting waste management from disposal-oriented practices toward value creation and sustainability (Kirchherr et al., 2017). These concepts are relevant because school-based waste management should not only be understood as a technical activity, but also as an educational process that shapes environmental awareness and sustainable behavior.

However, existing waste management literature is still predominantly focused on macro-scale systems, particularly municipal solid waste management, technical infrastructure, and waste processing technologies. Such studies tend to emphasize engineering and operational aspects, while social, institutional, and educational dimensions are less integrated. From the perspective of integrated sustainable waste management, system effectiveness depends not only on technology but also on governance effectiveness and behavioral change within communities (Guerrero et al., 2013; Ferronato & Torretta, 2019). Therefore, educational institutions, particularly schools, have a strategic role in fostering environmental awareness and sustainable behavior from an early age.

In Indonesia, the Adiwiyata program was developed to integrate environmental values through school policies, curriculum implementation, and participatory activities. Nevertheless, the implementation of school-based waste management still faces several challenges, including limited facilities, weak institutional systems, and insufficient integration between waste management practices and learning processes (Firmansyah & Kurniawan, 2024; Lestari & Wijaya, 2024). Waste management practices in schools are often still fragmented and limited to cleaning activities, waste sorting, composting, or school waste banks. These practices have not yet been developed into a comprehensive model that integrates institutional, operational, financial, evaluative, and learning dimensions.

Previous studies indicate significant research gaps in three main dimensions. Empirically, waste management research remains concentrated on macro-scale systems, while studies at the micro level, such as educational institutions, remain limited (Ferronato & Torretta, 2019). Conceptually, there is still no comprehensive model that integrates waste-to-energy, environmental education, and governance frameworks into a unified school-based system. Methodologically, previous studies have generally applied single approaches, whereas the integration of systematic literature review (SLR) and bibliometric analysis in conceptual model development remains limited (Donthu et al., 2021). Therefore, this study assumes that the integration of WtE, environmental education, and institutional governance can support the development of a more sustainable school-based waste management system.

Based on this condition, this article needs to clarify its direction through explicit research questions. This study is formulated to answer four main questions:

1. What publication trends have emerged in studies related to sustainable waste management, WtE, environmental education, and Adiwiyata schools?
2. What dominant thematic clusters can be identified in the literature on sustainable waste management based on bibliometric analysis?
3. What research gaps exist regarding the integration of WtE, school-based waste management, and environmental education?
4. How can the results of SLR and bibliometric analysis be used to develop a conceptual model of integrated waste management for Adiwiyata schools?

The novelty of this study lies in the integration of four main elements: WtE, Adiwiyata schools, SLR, and bibliometric analysis to develop an evidence-based school waste management model. The novelty is not merely stated as a conceptual claim but is demonstrated through literature mapping and systematic synthesis. Theoretically, this study extends WtE studies from a technical context to an educational context. Methodologically, it applies to a combination of PRISMA-based SLR and bibliometric analysis using VOSviewer to identify publication trends, thematic clusters, and research gaps in a more measurable way. Practically, this study provides a conceptual basis for a waste management model that can support the implementation of Adiwiyata more systematically, not merely as a school cleanliness program but as part of sustainable environmental education.

Based on these gaps, this study aims to analyze the development of literature related to sustainable waste management, WtE, environmental education, and Adiwiyata schools and to develop an integrated waste management model based on the waste-to-energy approach within the context of Adiwiyata schools. The proposed model is expected to integrate institutional, operational, financial, monitoring-evaluation, and educational dimensions. Through this model, waste management in schools can function not only as an environmental management practice but also as a contextual learning instrument that strengthens students' environmental awareness and sustainable behavior.

METHODS

This study employed a systematic literature review (SLR) combined with bibliometric analysis to examine sustainable waste management research and to formulate an integrated waste-to-energy-based waste management model for Adiwiyata schools. The literature selection process followed the PRISMA 2020 guidelines (Page et al., 2021), covering identification, screening, eligibility, and inclusion stages. This approach was used to ensure that the selected literature was systematically identified, filtered, and synthesized based on clear criteria. The literature search was conducted on 1 April 2026 using the Scopus database. Scopus was selected as the sole data source because it provides structured and reliable bibliographic metadata suitable for bibliometric analysis. The search was performed in the Title, Abstract, and Keywords fields using Boolean operators. The main search string was:

TITLE-ABS-KEY ("waste management" OR "municipal solid waste") OR "solid waste management" OR "school waste" OR recycling OR composting) AND TITLE-ABS-KEY

("waste-to-energy" OR "WtE") OR "energy from waste" OR "waste conversion" OR incineration OR "anaerobic digestion" OR biogas) AND TITLE-ABS-KEY ("environmental education" OR "Adiwiyata school" OR "green school" OR "sustainable school" OR school OR students).

The inclusion criteria were articles published between 2006 and 2025, peer-reviewed journal articles, conference papers, or review articles, studies related to waste management, waste-to-energy, environmental education, green schools, sustainable schools, or Adiwiyata schools, and publications with complete bibliographic metadata. The exclusion criteria included duplicate records, irrelevant studies, articles with insufficient information, and non-scientific documents such as news articles, blogs, theses, dissertations, and unpublished reports.

At the identification stage, 420 records were retrieved from Scopus. After removing 20 duplicate records, 400 records were screened based on titles and abstracts. A total of 200 records were excluded because they were not relevant to the research focus. The remaining 200 full-text articles were then assessed for eligibility. Of these, 50 articles were excluded, consisting of 35 articles that did not meet the inclusion criteria and 15 articles with insufficient data or information. Finally, 150 studies were included in the qualitative synthesis, and 133 articles were selected for bibliometric analysis using VOSviewer. The selection process is presented in Figure 1.

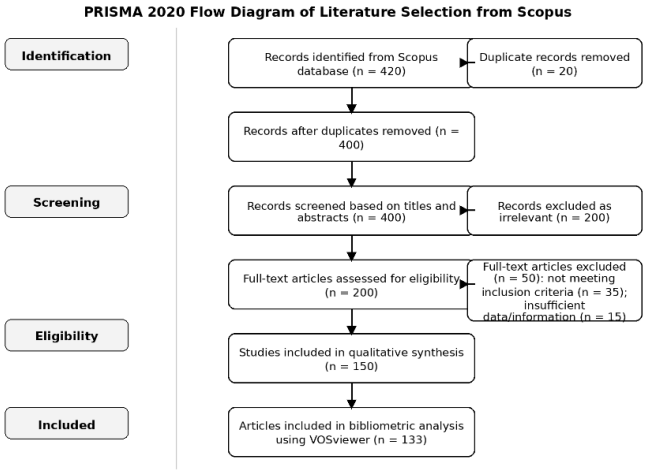

Figure 1 PRISMA 2020 flow diagram of the study

Before conducting the bibliometric analysis, data cleaning was carried out to improve the accuracy and consistency of the dataset. The Scopus data was exported in CSV format and checked using Microsoft Excel and Mendeley. Duplicate records were removed based on DOI, title, first author, and publication year. Similar terms, such as “waste-to-energy,” “waste to energy,” and “WtE,” were standardized to avoid keyword fragmentation and to improve the accuracy of keyword mapping.

Bibliometric analysis was conducted using VOSviewer version 1.6.20 (van Eck & Waltman, 2010). The analysis covered publication trends, productive authors, institutional affiliations, country distribution, document types, subject areas, keyword co-occurrence, overlay visualization, and density visualization. The co-occurrence analysis used author keywords and index keywords, with full counting and a minimum threshold of three keyword occurrences. The results of the bibliometric analysis were then integrated with qualitative synthesis to identify major themes and research gaps and to support the development of the proposed conceptual model.

The integration of SLR and bibliometric analysis was applied to strengthen the evidence base of the study. The SLR was used to systematically synthesize previous studies, while bibliometric analysis was used to map publication trends, research networks, and thematic structures in literature. Through this combined approach, the study not only describes the development of

research on sustainable waste management and WtE but also identifies the extent to which these topics have related to Adiwiyata schools and environmental education.

RESULT AND DISCUSSION

Publication Trends

The publication trend shows that studies related to sustainable waste management and waste-to-energy developed gradually during the 2007–2018 period and increased sharply after 2019 (see Figure 2). Based on the bibliometric data, the number of publications was relatively low in the early period, ranging from 1 to 6 documents per year between 2007 and 2018. The lowest number of publications was recorded in 2011 with only 1 document, while the highest number before 2019 was recorded in 2014 with 6 documents. A clear increase began in 2019, with 10 documents published. This upward trend continued in 2020 with 12 documents and 2021 with 14 documents and reached the highest point in 2022 with 16 documents. In 2023, the number of publications decreased to 11 documents but increased again in 2024 to 15 documents (see Table 1). This pattern indicates that the topic has gained stronger research attention in recent years, especially after 2019.

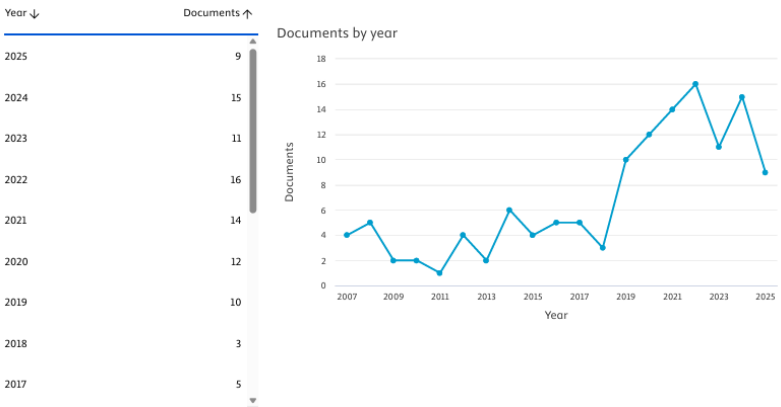

Figure 2. Publication trends (2006-2025)

Table 1. Publication trends by year

Year	Number of Documents
2007	4
2008	5
2009	2
2010	2
2011	1
2012	4
2013	2
2014	6
2015	4
2016	5
2017	5
2018	3
2019	10
2020	12
2021	14
2022	16
2023	11
2024	15

The increase in publications reflects growing academic attention to sustainable waste management and WtE as part of the global sustainability agenda. The rising volume of global waste has intensified the need for innovation in waste management systems, particularly in developing countries (Kaza et al., 2018). In this context, the trend also reflects a shift from conventional waste disposal toward resource recovery and circular economy approaches. This is consistent with previous studies that emphasize that WtE can support waste reduction, alternative energy generation, and resource efficiency within sustainable waste management systems (Chen et al., 2020; Alao et al., 2022).

However, the publication trend alone does not directly prove the integration of WtE, Adiwiyata, environmental education, and school governance. Most studies still focus on macro-scale waste management and technical waste processing, while school-based waste management and educational dimensions remain limited. From the perspective of sustainability transition, environmental system transformation requires cross-sector integration, including the education sector (Geels, 2011). Therefore, this finding supports the need to combine publication trend analysis with keyword co-occurrence, thematic clusters, subject areas, and literature synthesis to justify the development of an integrated waste management model for Adiwiyata schools.

Productive Authors

The analysis of productive authors was conducted to identify the most influential researchers and publication productivity patterns in the field of sustainable waste management. The results indicate that research productivity in this field is still relatively limited, reflecting that school-based waste management studies remain an emerging research area within the global scientific community.

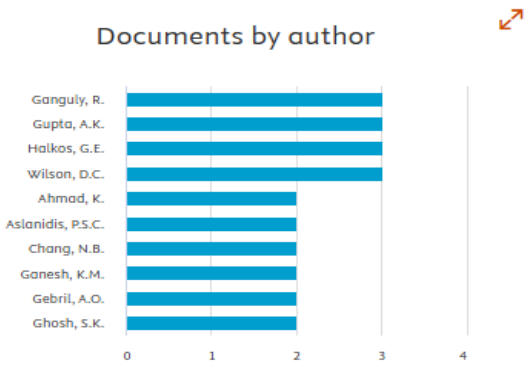

Figure 3. Productive authors

Figure 3 shows that author productivity in this field remains relatively low, with a maximum of only 3–4 publications per author. This finding indicates that school-based waste management has not yet become a major focus within the global scientific community. Such a pattern is commonly found in emerging research fields, characterized by a low concentration of publications among specific authors and the absence of dominant research groups (Donthu et al., 2021; Zupic & Čater, 2015).

In addition, the dominance of authors from developing countries such as India suggests that waste management issues are strongly associated with the environmental challenges faced by these countries. This finding is consistent with Guerrero et al., (2013) and Ferronato and Torretta (2019), who stated that developing countries tend to become major centers for waste management studies due to the high pressure on their waste management systems. However, the absence of Indonesian researchers among the most productive authors indicates a gap in scientific contribution, despite Indonesia having long implemented the Adiwiyata program. This condition reflects a geographical research gap between environmental policy practices and academic contributions, where the implementation of environmental programs has not been fully supported

by scientific publication outputs. These findings highlight the urgency of developing research based on local contexts to strengthen Indonesia's contribution to global literature (Kaza et al., 2018; Ferronato & Torretta, 2019).

Institutional Affiliations

The affiliation analysis from Figure 4 demonstrates the dominance of institutions from developed countries and several developing countries, such as India and European nations, in publications related to waste management. The absence of Indonesian institutions among the leading affiliations indicates that national scientific contributions remain limited within international literature. This pattern reflects global inequality in environmental knowledge production, where countries with stronger research infrastructure and more advanced waste management systems tend to dominate scientific publications (Kaza et al., 2018; UNEP, 2015). Furthermore, the unequal distribution of publications is also associated with differences in waste management capacities among countries. Developing countries often face limitations in technology, institutional systems, and financial resources, which consequently reduce their scientific contributions to global literature (Wilson et al., 2015). This condition suggests that severe environmental problems are not always accompanied by adequate research production.

In the Indonesian context, the limited representation of national institutions in international publications indicates the existence of geographical and structural research gaps, particularly in integrating national environmental policy practices into scientific studies. In fact, Indonesia has environmental education programs such as Adiwiyata that could provide unique contributions to global literature. Therefore, school-based research plays a strategic role in bridging the gap between local practices and scientific knowledge development in sustainable waste management.

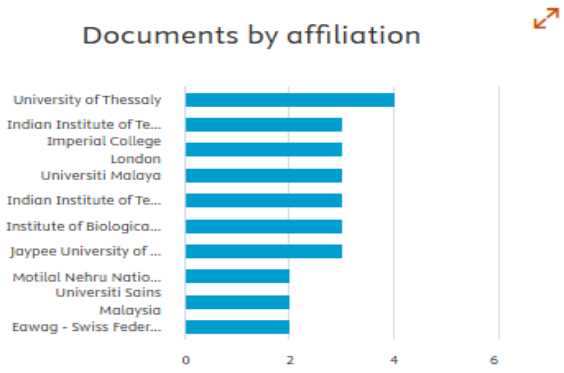

Figure 4 Institutional affiliations

Country Distribution

The distribution of publications shown in Figure 5 indicates the dominance of countries such as India, Malaysia, and the United States in waste management research. The absence of Indonesia among the top ten contributing countries highlights a gap between policy implementation and scientific contribution. In fact, Indonesia is one of the countries facing significant waste management problems. Data from the Ministry of Environment and Forestry (2025) indicate that a large proportion of national waste is still not properly managed, emphasizing the need for innovative and system-based approaches. Therefore, this study provides an important contribution to strengthening Indonesia's scientific representation in global literature, particularly in the context of sustainable school-based waste management and environmental education.

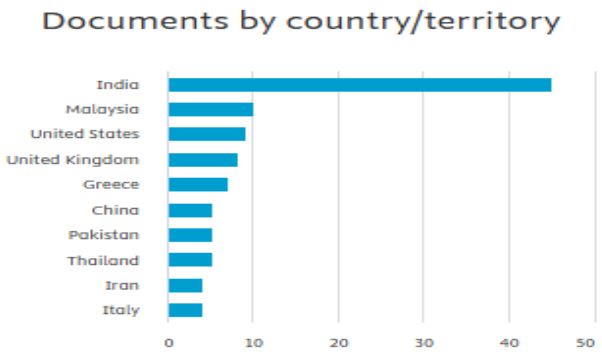

Figure 5 Country distribution

Document Types

The analysis of document types (See Figure 6) shows that publications are dominated by journal articles (67.8%), followed by conference papers (12.4%), book chapters (12.4%), and review articles (7.4%). The dominance of journal articles indicates that waste management research has developed toward empirical studies focusing on data analysis and practical implementation. This pattern is commonly found in fields that have entered the application development stage, where research emphasizes solution validation rather than conceptual exploration (Chen et al., 2020).

However, the relatively low proportion of review articles suggests that knowledge synthesis in this field remains limited. In fact, systematic review and bibliometric studies play an important role in identifying research trends, mapping knowledge structures, and systematically detecting research gaps (Donthu et al., 2021; Zupic & Čater, 2015). The limited number of synthesis studies indicates that research development in this field is still fragmented and has not yet been integrated into a strong conceptual framework. In addition, the relatively high proportion of conference papers indicates that some studies are still at an early or exploratory stage and have not yet developed into reputable journal publications. This finding further confirms that the field is still evolving and requires stronger knowledge consolidation through more comprehensive synthesis studies (Waltman, 2016).

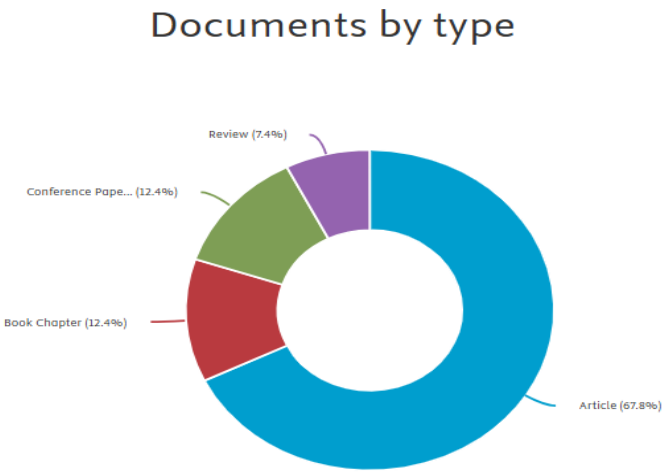

Figure 6 Document types

Subject Areas

The distribution of subject areas (see Figure 7) shows the dominance of environmental science (37.6%) and engineering (10.9%), followed by energy and computer science, while the

contributions from social sciences and education remain relatively low. This pattern indicates that waste management research is still primarily focused on technical and engineering approaches, particularly in the development of technology, waste treatment systems, and energy efficiency. Such dominance reflects the general characteristic of environmental studies, which tend to emphasize technical solutions rather than social and behavioral approaches (Chen et al., 2020). However, the limited contribution from social and educational fields indicates that waste management research has not yet fully adopted a multidisciplinary approach. In fact, the success of sustainable waste management systems strongly depends on the integration of social, institutional, and behavioral changes within society (Guerrero et al., 2013; Wilson et al., 2015). This finding suggests that technical approaches alone are insufficient to address the complexity of environmental problems. Furthermore, the low representation of educational studies indicates a gap in integrating learning systems with waste management practices. From a sustainability perspective, education plays a crucial role in shaping long-term environmental awareness and behavior, which are key factors in the effectiveness of environmental policy implementation (Leal Filho et al., 2018). Therefore, the limited contribution of educational perspectives in the literature highlights a significant multidisciplinary research gap.

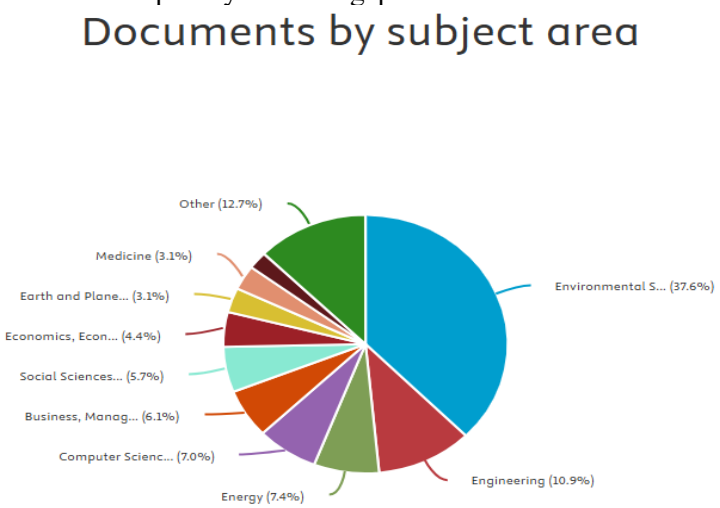

Figure 7 Subject areas

Co-occurrence Analysis

The co-occurrence analysis as seen from Figure 8 shows that the keywords *waste management* and *municipal solid waste* have high frequencies and central positions within the research network. This finding indicates the dominance of conventional approaches in existing literature. However, the emergence of keywords such as *waste-to-energy*, *carbon footprint*, and *sustainable development* reflects a shift toward sustainability-oriented approaches. This transition represents the movement toward a circular economy paradigm (Chen et al., 2020). Nevertheless, no strong linkage was identified between waste management topics and educational-related keywords. This finding indicates that the integration between waste management systems and educational dimensions remains limited within the current literature.

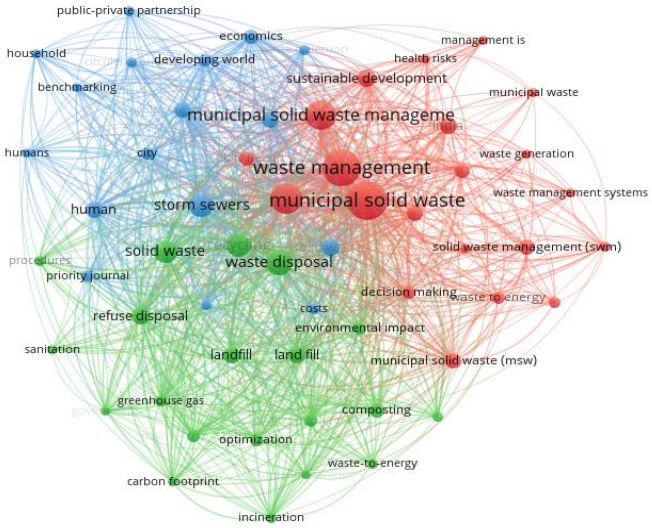

Figure 8 Co-occurrence analysis

Overlay Visualization

The overlay visualization analysis in Figure 9 indicates a shift in research focus from conventional approaches such as *waste disposal* and *landfill* toward sustainability-oriented approaches. In recent years, keywords such as *optimization*, *carbon footprint*, and *waste-to-energy* have become more dominant, reflecting a transition toward circular economy concepts and system efficiency (Chen et al., 2020; Kirchherr et al., 2017). However, no significant relationship was identified between recent research developments and educational aspects. This finding suggests that the educational dimension has not yet become an integral part of the evolution of waste management research, indicating the existence of a temporal research gap that underlies the development of the school-based model proposed in this study.

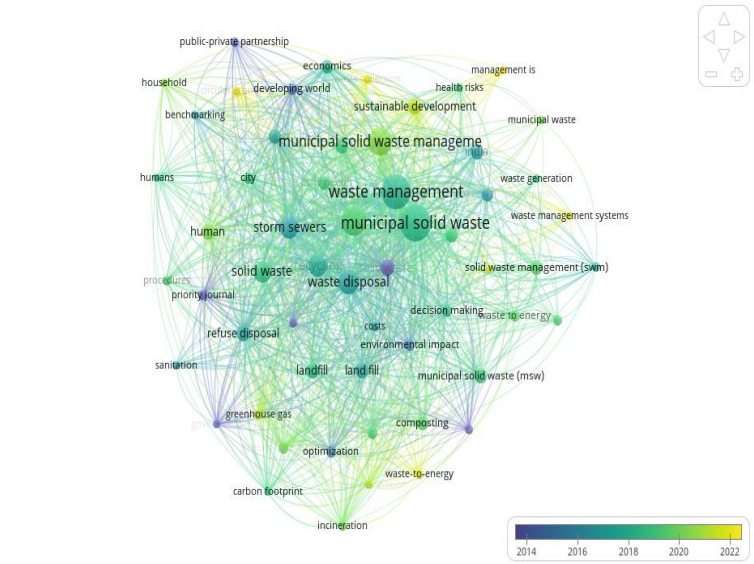

Figure 9 Overlay visualization

Density Visualization

The density visualization analysis from Figure 10 shows that the keywords "waste *management" and "municipal solid waste"* have high density levels, confirming the dominance of conventional

approaches in waste management literature. High density was also identified for keywords such as "environmental *impact" and "decision-making,"* indicating that environmental evaluation and policy-making aspects have become important components in the development of modern waste management systems (Velis & Brunner, 2013; Marshall & Farahbakhsh, 2013). In contrast, keywords such as *waste-to-energy*, *carbon footprint*, and *sustainable development* appear in lower-density areas, suggesting that these topics are still evolving toward more integrated and sustainability-oriented system approaches. This finding is consistent with previous studies indicating that the transition toward energy-based waste management systems and emission mitigation remains in the strengthening phase within global literature (Arena, 2012; Astrup et al., 2015).

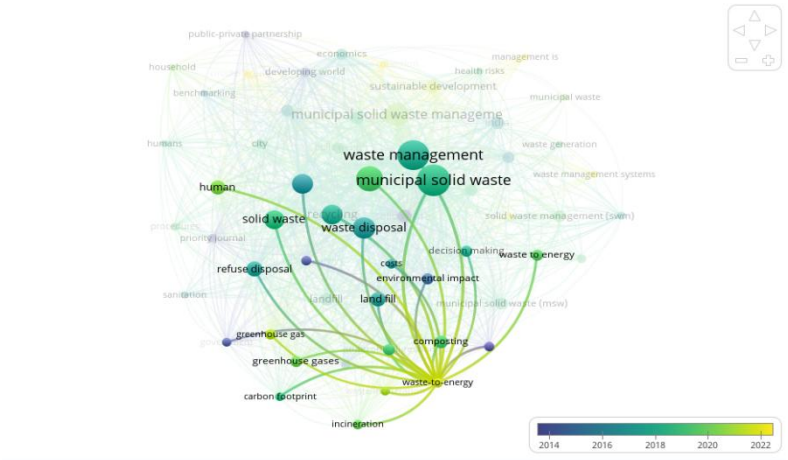

Figure 10. Density visualization

Conceptual Model of Integrated Waste-to-Energy-Based Waste Management

The operational component as illustrated by Figure 11 represents the core of the waste management system, covering waste segregation, collection, processing, and recycling activities.

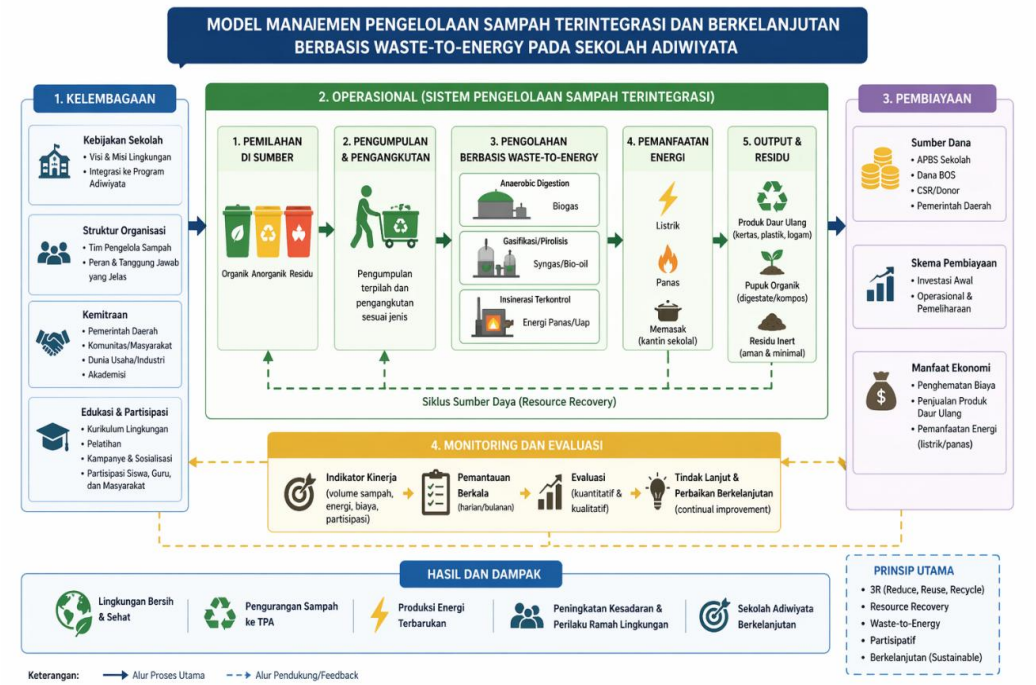

Figure 11 Conceptual model of integrated waste-to-energy-based waste management

In this stage, the waste-to-energy approach is positioned as the primary innovation distinguishing this model from conventional waste management approaches. The waste-to-energy component in this model is positioned through low-risk practices such as organic waste biodigesters, energy literacy activities, and partnerships with licensed external WtE facilities, rather than direct on-site incineration in schools. This finding aligns with previous studies indicating that municipal solid waste has substantial potential as an energy source, particularly due to its high organic content that can be converted into bioenergy (Okafor et al., 2022). In addition, the implementation of the waste-to-energy approach contributes to greenhouse gas emission reduction. In this context, renewable energy generated from waste processing has been shown to reduce carbon emissions and support environmental sustainability. Previous studies have demonstrated that the increased utilization of renewable energy and technological innovation is significantly associated with lower CO_2 emissions (Raihan et al., 2022).

However, WtE should not be understood as automatically sustainable. In the waste management hierarchy, the first priorities are waste reduction, reuse, recycling, and composting, while energy recovery should be considered only for residual waste that cannot be prevented, reused, or recycled (UNEP, 2019). Therefore, in the context of Adiwiyata schools, WtE should function as a complementary strategy rather than the main substitute for basic waste prevention and recycling practices.

The implementation of WtE also involves several trade-offs. Thermal technologies, particularly incineration, require strict emission control, advanced technology, skilled operation, high investment and operational costs, and proper ash residue management (Astrup et al., 2015; UNEP, 2019). These requirements make on-site incineration unsuitable for direct implementation in school environments. Therefore, this model emphasizes safer and more educationally relevant practices, such as waste sorting, reuse campaigns, school waste banks, recycling, composting, small-scale biodigesters for organic waste, energy literacy activities, and partnerships with licensed external WtE facilities. Through this approach, waste management in Adiwiyata schools can support both environmental performance and contextual learning by helping students understand waste reduction, resource recovery, emissions, costs, and environmental responsibility.

Furthermore, the financial component functions as a supporting factor that determines the sustainability of model implementation. Financial resources may originate from internal school funding, government support, and external partnerships. Moreover, outputs from waste processing, such as recycled products and generated energy, also have economic value that can contribute to the long-term financial sustainability of the program. The monitoring and evaluation component serves as a mechanism for control and continuous improvement. Through measurable performance indicators, such as waste reduction, cost efficiency, and increased participation of school communities, the program can be periodically evaluated to ensure implementation effectiveness.

Moreover, this model integrates educational and participatory aspects as essential elements within the Adiwiyata school context. Waste management is not merely viewed as a technical activity but also as a contextual learning medium capable of fostering students' environmental awareness and sustainable behavior. Previous studies have emphasized that environmental education plays a significant role in promoting sustainable behavior and strengthening students' ecological awareness within educational institutions (Filho et al., 2018; Ardoin et al., 2020). Therefore, the implementation of this model contributes not only to waste reduction but also to the development of a sustainable environmental culture within schools.

Overall, the proposed model reflects a paradigm shift from conventional waste disposal toward integrated sustainable waste management based on waste-to-energy principles. The main strength of this model lies in its ability to integrate multiple components into a connected system that is adaptive to educational institution contexts. Previous research has shown that integrated waste management systems and circular economy approaches are essential for improving environmental sustainability and long-term resource efficiency (Kirchherr et al., 2017; Chen et al., 2020). Thus, the findings of this study demonstrate that school-based waste management cannot be separated

from the systemic integration of institutional, operational, financial, and evaluative aspects. Therefore, the proposed quadruple system model not only addresses conceptual gaps in the literature but also offers a practical approach by integrating educational dimensions as a hidden curriculum within the Adiwiyata program.

CONCLUSION

This study shows that research on sustainable waste management and WtE has increased since 2019, but literature remains dominated by technical and macro-scale perspectives. The integration of WtE, Adiwiyata schools, and environmental education is still limited. The main contribution of this study is an integrated school-based waste management model consisting of institutional, operational, financial, monitoring-evaluation, and educational dimensions. The model positions waste management not only as a technical activity but also as contextual learning in Adiwiyata schools. This study is limited to a conceptual model based on Scopus-indexed literature, SLR, and bibliometric analysis. Therefore, future research should test the model in actual schools. Practically, schools should prioritize waste reduction, reuse, recycling, and composting, while WtE should be applied only through low-risk practices or partnerships with licensed external facilities.

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