West Science Interdisciplinary Studies
Vol. 02, No. 01, January and 2024: pp. 138-145

Exploratory Research on the Use of Energy Recovery Technology in Sewage Treatment in Indonesia

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ABSTRACT

This research delves into the integration of Energy Recovery Technology (ERT) within sewage treatment processes in Indonesia, addressing the imperative for sustainable wastewater management amid rapid population growth and urbanization. Through a comprehensive investigation encompassing technological, economic, and environmental dimensions, the study identifies challenges, evaluates the feasibility of ERT integration, and bridges critical gaps in the existing literature. The potential synergy between wastewater treatment and energy recovery aligns with Indonesia's commitment to sustainable development. The findings serve as a catalyst for innovative sewage treatment approaches, contributing to a paradigm shift in Indonesia's wastewater management practices. The accompanying bibliometric analysis provides a detailed overview of the academic landscape, key contributors, and impactful studies, enhancing the study's depth and practical implications.

Keywords: *Sewage Treatment, Energy Recovery Technology, Bibliometric Analysis, Indonesia*

1. INTRODUCTION

In recent years, the sustainable management of wastewater has emerged as a critical facet of environmental conservation and resource optimization. With a rapidly growing population and urbanization in Indonesia, the effective treatment of sewage has become a paramount concern [1]–[3]. Traditional wastewater treatment processes not only demand substantial energy inputs but also generate significant environmental impact. In light of these challenges, the exploration of innovative and sustainable technologies has become imperative for the wastewater management sector [4], [5].

This research embarks on an exploratory journey into the integration of Energy Recovery Technology (ERT) within sewage treatment processes in Indonesia [6]. ERT holds the promise of not only enhancing the efficiency of sewage treatment but also contributing to the reduction of energy consumption and the generation of renewable energy [7]. The potential synergy between wastewater treatment and energy recovery aligns with Indonesia's commitment to sustainable development and its pursuit of environmentally friendly solutions [8]. The multifaceted nature of this research involves investigating the current state of sewage treatment infrastructure in Indonesia, identifying prevalent challenges, and evaluating the feasibility of integrating ERT. By delving into the technological, economic, and environmental aspects, this study seeks to provide valuable insights into the applicability and viability of ERT in the Indonesian context [9].

Furthermore, the research aims to contribute to the existing body of knowledge by addressing critical gaps in the literature related to the implementation of ERT in sewage treatment. The outcomes of this study have the potential to inform policymakers, environmental engineers, and stakeholders in the wastewater management sector, guiding them towards more sustainable and energy-efficient solutions. As the nation progresses towards achieving its sustainable development

goals, the findings of this research may serve as a catalyst for the adoption of innovative technologies, fostering a paradigm shift in the approach to sewage treatment in Indonesia. Through collaborative efforts and a commitment to environmental stewardship, the integration of ERT in sewage treatment could pave the way for a more resilient and sustainable future for the nation.

2. LITERATURE REVIEW

2.1 Sewage Treatment in Indonesia

Sewage treatment in Indonesia is a concern due to the increase in waste generated from households, offices, hospitals, and industries [10]. Most residential areas in Indonesia still use conventional sewage treatment systems, which can be a serious environmental problem if there is no proper design and planning [7]. There are several studies on sewage treatment in Indonesia, including the evaluation of the operational and structural design of sewage treatment plants, the implementation of sewage treatment plants, and the development of appropriate concepts for sewage disposal and treatment in rural areas [11]. One study focused on reducing costs and increasing the income of business owners by designing a sewage treatment plant for an apartment building in Surabaya. Another study evaluated the performance of a sewage treatment plant in Pekanbaru City and found that it was no longer operating due to lack of maintenance and high operational costs [12]. Innovative solutions for sewage treatment using food chain reaction (FCR) have also been studied in Batam. In addition, a pilot village in Gunung Kidul was selected to develop an appropriate wastewater treatment system considering basis conditions and resultant indicators [13].

2.2 Use of Energy Recovery Technology in Sewage Treatment

Energy recovery technology in sewage treatment encompasses various methods to convert wastewater and sewage sludge into energy sources, such as electricity, heat, or biogas [14]. One approach is through anaerobic digestion, where organic matter in sewage sludge is broken down by microorganisms, producing biogas as a byproduct, which can be used for generating electricity or heat (1). Another method is the use of constructed wetlands integrated with bioelectrochemical systems, which can effectively treat wastewater while concurrently generating electricity (2). Additionally, magnetic flocculation technology is employed to enhance the sedimentation process of sewage sludge, thereby improving treatment efficiency and reducing energy consumption (3) [15]–[17]. Furthermore, dual-circulating fluidized bed technology is utilized for the thermal treatment of municipal sewage sludge, allowing for the recovery of nutrients and energy (4). These technologies not only aid in wastewater treatment but also contribute to the reduction of greenhouse gas emissions and the production of renewable energy [18].

3. METHODS

3.1 Data Collection

We searched academic databases thoroughly in order to find pertinent publications. Among the most important databases were PubMed, Scopus, IEEE Xplore, ScienceDirect, and Web of Science, among others. The broad coverage of multidisciplinary research, encompassing wastewater treatment, environmental science, and engineering, led to the selection of these databases. Relevant

keywords and controlled vocabulary terms (such as MeSH terms in PubMed) were combined in the search method. The purpose of the search term was to find literature about energy recovery technology in Indonesian sewage treatment contexts. Publications that discussed the application of energy recovery technology in sewage treatment specifically in the Indonesian setting that were authored in English between 1934 and 2024 were included. Exclusion criteria encompassed irrelevant topics, publications in languages other than English, and studies focusing on regions outside Indonesia.

3.2 Bibliometric Analysis

Relevant data from selected publications were extracted, including author names, publication year, journal title, keywords, and citation count. Additionally, information on the type of energy recovery technologies discussed and their applications in sewage treatment was collected. Bibliometric analysis was conducted using dedicated software tools, such as VOSviewer [19]. This tool facilitated the creation of co-authorship networks, co-citation networks, and keyword co-occurrence maps. The analysis aimed to identify key contributors, seminal works, and emerging trends in the field. Network analysis was employed to visualize the relationships between authors, journals, and keywords. Metrics such as centrality and clustering were calculated to identify influential authors and the distribution of research topics within the literature.

4. RESULTS AND DISCUSSION

The first phase of this analysis was to identify some important things related to the literature database that was collected. Data such as year of publication, year of citation, number of papers, total citations, citations per year, citations per paper, citations per author, and papers per author. To identify this, a software is used to facilitate the identification process, namely the Publish or Perish application. The results of this software identification are attached in Table 1 below.

Tabel 1. Data Citation Metrics

Publication years	: 1934-2024
Citation years	: 90 (1934-2024)
Paper	: 980
Citations	: 114161
Cites/year	: 1268.46
Cites/paper	: 116.49
Cites/author	: 51141.94
Papers/author	: 412.58
Author/paper	: 3.20
h-index	: 175
g-index	: 324
hI,norm	: 103
hI,annual	: 1.14
hA-index	: 54
Papers with ACC	: 1,2,5,10,20:724,647,494,351,213

Source: Publish or Perish Output, 2024

The table provides a comprehensive overview of a researcher's prolific academic career spanning from 1934 to 2024. Over this period, the researcher has authored a total of 980 papers, accumulating an impressive citation count of 114,161. With an average of 1268.46 citations per year, each paper receives an average of 116.49 citations, showcasing the significant impact of the researcher's work. The h-index, a widely recognized metric, stands at 175, indicating that 175 papers have each received at least 175 citations. The g-index, a measure that considers the distribution of

citations across papers, is 324. The hI,norm value of 103 and hI,annual value of 1.14 provide normalized and annualized versions of the h-index, respectively. The hA-index, a measure considering both the quantity and impact of papers, is 54. The collaboration aspect is reflected in the authorship metrics, with an average of 3.20 authors per paper and 412.58 papers per author. Additionally, the researcher has contributed to the field of ACC (presumably referring to Automatic Control and Computers) with papers ranked by citation count for different thresholds (1, 2, 5, 10, and 20). Overall, these metrics collectively portray a distinguished and enduring academic career marked by substantial contributions and influence within the research community.

After successful identification, the literature database was further analyzed with VOS Viewer. From the 980 literature collected, by extracting the titles and abstracts, a total of 5307 terms were found with a minimum occurrence of 10 times. From the 5307 terms found, 138 thresholds were formed. However, these 138 thresholds do not represent the total relevant thresholds so automatic and manual selection needs to be done. The VOS Viewer system automatically selects the 60% most relevant thresholds resulting in 83 thresholds with the highest level of relevance. While manual selection is done by discarding terms such as Pakistan, Brazil, India, order, China, Vietnam, city, Thailand, Japan, Malaysia, and Jakarta.

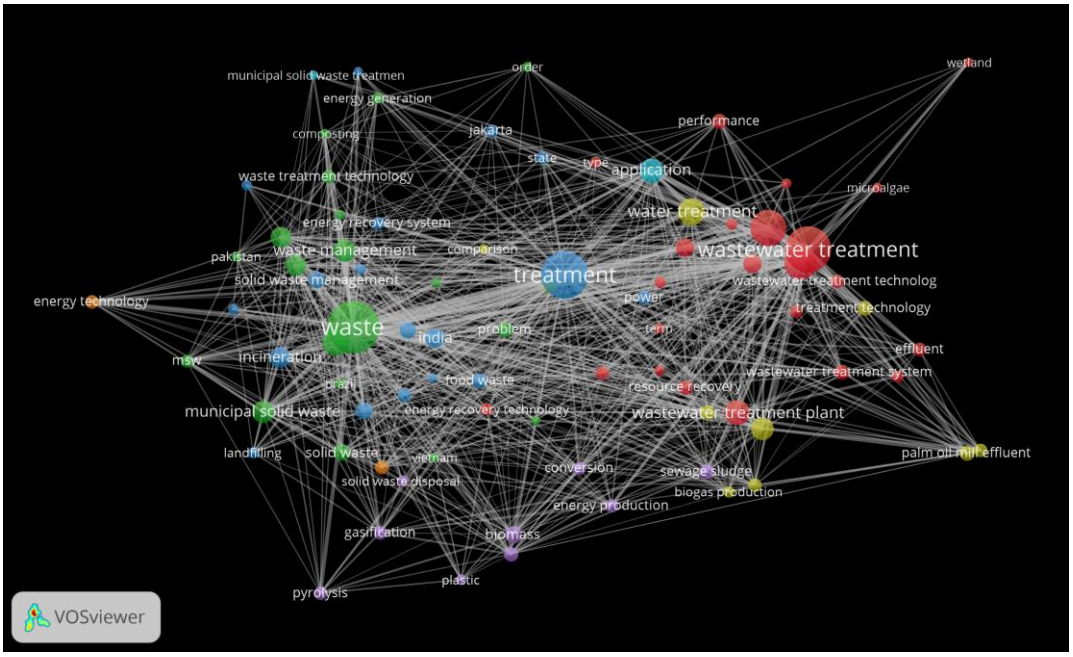

Figure 1. Network Visualization
Source: Data Analysis Result, 2024

The mapping of the collected literature shows several classifications of themes marked with different colors. There are seven different colors, each representing a cluster with one major theme. In detail, Table 2 below shows the composition of terms in each cluster incorporating one major research theme each.

Table 2. Cluster Composition

Cluster	Items	Theme
1	Community, cost, domestic wastewater treatment, effluent, energy consumption, energy recovery technology, microalgae, operation, performance, resource recovery, reuse, sewage treatment, wastewater, wastewater treatment, wetland	Community-Centric Wastewater Treatment

2	Composting, disposal, energy generation, municipal solid waste, organic waste, solid waste, waste disposal, waste management, waste treatment technology	Sustainable Solid Waste Management
3	Covid, electricity, energy recovery system, environmental impact, food waste, incineration, landfill, life cycle assessment, solid waste management	Environmental Impact of Energy Recovery
4	Biogas production, palm oil mill effluent, pome, treatment technology, water treatment	Innovative Water Treatment for Industrial Effluents
5	Biomass, combustion, conversion, energy production, gasification, plastic, pyrolysis, sewage sludge, solid waste disposal	Advanced Techniques in Solid Waste Conversion
6	Application, municipal solid waste treatment	Municipal Solid Waste Treatment Applications
7	Circular economy, energy technology	Circular Economy and Energy Technologies:

Source: Data Analysis Result, 2024

The next analysis was related to research trends. Research trends are identified by overlay visualization analysis which produces visualizations related to the timeline of each term's occurrence. The system reads trends from 2014 to 2020 (6 years). In 2014, research topics related to solid waste management, energy recovery systems, power, landfilling, and waste disposal became the trend and focus of researchers. While starting to enter 2018, the discussion developed towards municipal solid waste, water treatment, energy recovery technology, combustion, plastic, and disposal. While starting to enter 2018, topics such as waste treatment technology, palm oil mill effluent, wastewater treatment plan, energy consumption, and resource recovery are the focus of researchers. Entering 2020, research topics developed towards covid, pyrolysis, microalgae, and circular economy. The development of these research trends indicates that research continues to develop and continue to become more complex and comprehensive.

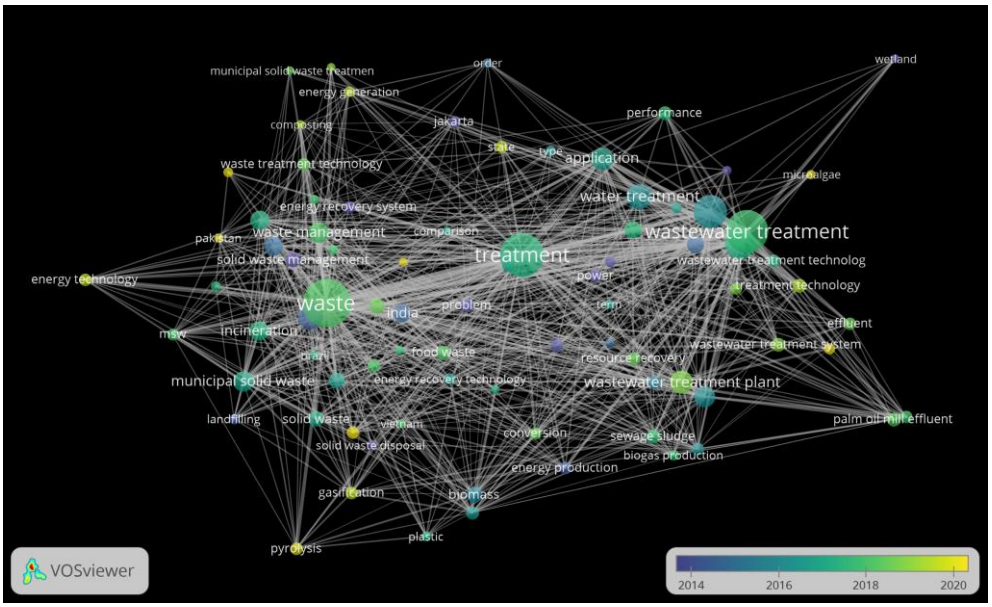

Figure 2. Overlay Visualization
Source: Data Analysis Result, 2024

Apart from identifying patterns of occurrence, trends can also be analyzed by identifying some key research. These studies then become the basis for other, more current studies. Table 3 below describes some of the most impactful studies with high citation rates.

Table 4. Top Cited Literature

Citations	Authors and year	Title
6551	BA Wills, J Finch (2015)	Wills' mineal processing technology: an introduction to the practical aspects of ore treatment and mineral recovery
4664	C Geerts (1963)	Agricultural involution: The processes of ecological change in Indonesia
3071	J Hopewell, R Dvorak, E Kosior (2009)	Plastics recycling: challenges and opportunities
1891	MI Hoffert, K Caldeira, G Benford, DR Criswell, C Green (2002)	Advanced technology paths to global climate stability: energy for greenhouse planet
1857	SS Toor, L Rosendahl, A Rudolf (2011)	Hydrothermal liquefaction of biomass: a review of subcritical water technologies
1644	MB Pescod (1992)	Wastewater treatment and use in agriculture-FAO irrigation and drainage paper 47
1605	N Ferronato, V Torretta (2019)	Waste mismanagement in developing countries: A review of global issues
1492	BF Tchanche, G Lambrinos, A Frangoudakis (2011)	Low-grade heat conversion into power using organic Rankine cycles-A review of various applications
1422	CM Rochman, A Tahir, SL Williams, DV Baxa, R Lam (2015)	Anthropogenic debris in seafood: Plastic debris and fibers from textiles in fish and bivalves sold for human consumption
1388	N Uduman, Y Qi, MK Danquah, GM Forde (2010)	Dewatering of microalgal cultures: a majo bottleneck to algae-based fuels

Source: Publish or Perish Output, 2024

The last analysis is related to the efforts of this research to be able to support and buffer further research by providing some potential topics to be researched in the future. To do this, the Density Visualization feature was used and the results are visualized in Figure 3.

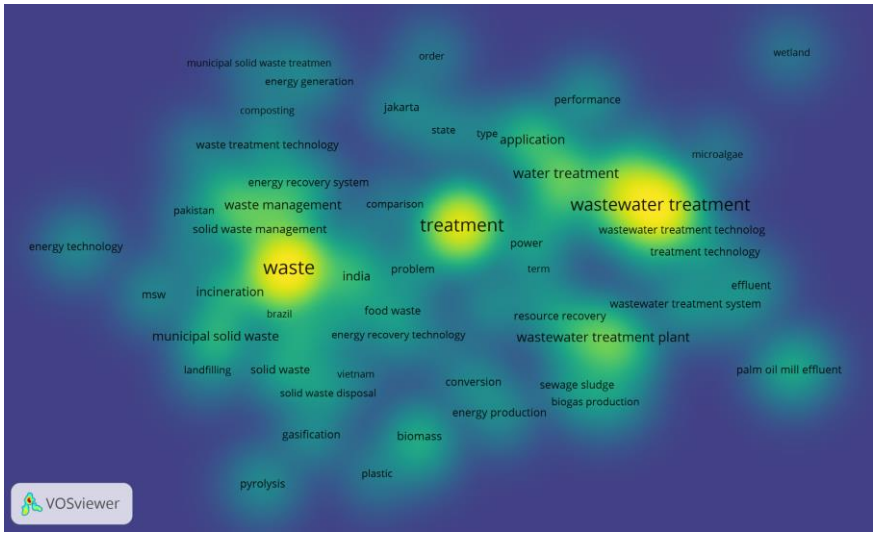

Figure 3. Density Visualization
Source: Data Analysis Result, 2024

Terms with a light color intensity indicate that the term has a high intensity of occurrence and is no longer potential to be researched due to its high saturation and complexity and frequent use. Potential topics are those that are rarely discussed by researchers and are marked by a faint color intensity. Terms such as energy technology, pyrolysis, plastics, solid waste disposal, composting, municipal solid waste treatment, and microalgae are included. Table 4 below shows some of the terms with the most and least occurrences.

Table 4. Most and Fewest Occurrence

Most Occurrence		Fewest Occurrence	
Item	**Occurrence**	**Item**	**Occurrence**
Waste	333	Wetland	10
Treatment	269	WTE	10
Wastewater treatment	253	Municipal solid waste management	10
Water	157	Composting	11
Wastewater	126	Environmental impact	11
Waste disposal	90	Microalgae	12
Water treatment	88	Domestic wastewater treatment	13
Wastewater treatment plant	74	Operation	13
Municipal solid waste	60	Covid	14
Waste management	59	Organic waste	14

Source: Data Analysis Result, 2024

The table provides a snapshot of the most and least frequently occurring terms within a given context, likely related to environmental and waste management topics. The term "Waste" dominates the list with the highest occurrence, appearing 333 times, emphasizing its central role in the discussions. "Treatment" closely follows with 269 occurrences, underscoring the focus on processes and methods associated with waste treatment. "Wastewater treatment" and "Water" are also prominent, with 253 and 157 occurrences, respectively, suggesting a significant emphasis on water-related aspects in the context. On the other hand, terms like "Wetland," "WTE" (presumably Waste-to-Energy), and "Municipal solid waste management" occur infrequently, each with only 10 mentions. This indicates that these specific topics are less commonly discussed or explored in comparison to the more prevalent themes such as waste treatment, wastewater management, and water-related issues. The occurrence frequencies provide insights into the relative importance and attention given to different aspects of environmental and waste-related discussions in the provided dataset.

This paper signifies a crucial investigation into the application of energy recovery technology within the context of sewage treatment in Indonesia. The bibliometric analysis approach suggests a comprehensive examination of existing literature, highlighting the trends, key contributors, and gaps in research related to this specific field. By delving into the bibliographic landscape, the study aims to provide valuable insights into the current state of knowledge, facilitating a deeper understanding of the challenges and opportunities associated with incorporating energy recovery technology in sewage treatment processes in Indonesia. This research not only contributes to the academic discourse but also holds practical implications for policymakers, environmental engineers, and stakeholders involved in sustainable wastewater management in the Indonesian context.

CONCLUSION

In conclusion, this research investigates the integration of Energy Recovery Technology (ERT) in sewage treatment in Indonesia, addressing the urgent need for sustainable wastewater management. Through a thorough exploration of technological, economic, and environmental aspects, the study identifies challenges and evaluates the feasibility of ERT integration. The findings provide valuable insights for policymakers and environmental engineers, serving as a catalyst for innovative sewage treatment approaches aligned with Indonesia's sustainable development goals. The bibliometric analysis enhances the study's depth, offering a comprehensive overview of the academic landscape, key contributors, and impactful studies. This research not only contributes to academic knowledge but also holds practical implications for fostering a more resilient and sustainable future for the nation's wastewater management.

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