Environmental Information Technology-Based Waste Management

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Abstract. The population and economic growth in Pati Regency are directly proportional to the amount of waste generated. The increase in waste volume sent to landfills, along with rising waste generation and management services, impacts the landfill's lifespan. This study aims to analyze the waste management system at the Pati Regency landfill, evaluate the performance and expectations of environmental information technology-based waste management planning, and develop such planning at the Pati landfill. The research uses evaluation methods, collecting data through questionnaires, interviews, observations, documentation, and literature review. Instrument testing ensures validity and reliability. Samples were selected using proportional random and purposive sampling techniques. Data analysis includes quantitative methods using Importance Performance Analysis (IPA) and qualitative methods by Miles and Huberman. The results show waste management at Sukoharjo landfill is planned and organized, involving various stakeholders. It includes waste reduction, processing, transportation, and closure in line with SOPs. The performance is high (86.27%), with customer expectations also high (92.85%). Most aspects meet expectations, except waste sorting and processing (negative gap). The difference between performance and expectations is significant (t-calculated 7.169 > t-table 1.658). Improvements should focus on organizing and implementing waste management. Environmental Information Technology (EIT)-based management achieves 80.03% performance and 87.13% expectations. The difference test is significant (t-calculated 4.315 > t-table 1.658). However, creating waste management flowcharts and maintaining technology systems require improvement.

Keywords: Waste Management, Pati Regency TPA, Environmental Information Technology, Natural Science.

1 Introduction

Waste management plays a crucial role in environmental sustainability and public health. It is a systematic, comprehensive, and continuous process involving waste reduction and management [1], encompassing collection, separation, transfer, transportation, processing, and final disposal to prevent environmental contamination [2]. The

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objectives of waste management include improving public health, preserving environmental quality and functions, raising public awareness of healthy lifestyles, and transforming waste into valuable resources with economic benefits [1,3]. Waste management functions encompass managerial aspects such as planning, organizing, controlling, evaluating, and monitoring [4], as well as operational functions including generation, handling, collection, transfer, separation, and final processing. The benefits of waste management include improved environmental health and enhanced economic opportunities for communities.

Given the objectives, functions, and benefits outlined above, it is evident that waste management plays a pivotal role. Several fundamental factors underpin the need for effective waste management, including: increasing waste generation, environmental impacts, disease prevention, promotion of a circular economy, improved quality of life, environmental sustainability, geographic conditions, landfill capacity, and public participation.

While waste management is crucial for environmental sustainability and public health, its implementation often falls short of optimal levels. Data from the Environmental Agency indicates a growing volume of waste in Pati Regency, increasing from 269.83 tons/day in 2021 to 272.21 tons/day in 2022. However, the Sukoharjo landfill's capacity to manage waste only covers 35.53% of the entire regency, falling short of the Regional Strategic Policy (Jakstrada) target of 70% waste handling by 2025 [5]. A 2019 report revealed that the Sukoharjo landfill receives an average of 50,146 tons of waste per day with an initial density of 243.05 kg/m³, equivalent to a volume of 206 m³. Evaluations of waste management at the landfill indicate that it has not been optimally managed, relying solely on the sanitary landfill method [6].

The data indicates that waste management at the Sukoharjo landfill is suboptimal. Several factors contribute to this issue, including: low public awareness and participation, unclear regulations, weak law enforcement, an inadequate organizational structure for waste management, and a negative attitude among waste management personnel [7]. Additional factors contributing to the problem are a lack of public awareness and participation in source reduction and the limited practice of the 3R principles (reuse, reduce, recycle); and, inadequate management of domestic wastewater [8].

The suboptimal waste management at the Sukoharjo landfill in Pati Regency has led to several adverse consequences, including: foul odors and unsightly appearances, unmanaged waste piles, deteriorating health conditions, and increased risks of flooding and landslides [6].

Pati Regency has endeavored to address this issue by enacting Regional Regulation No. 7 of 2010 on Waste Management, which mandates the implementation of the 3R concept (Reduce, Reuse, Recycle) through the provision of segregated waste bins. However, the effectiveness of this regulation has been limited due to the lack of supporting information technology. Consequently, there is a need to explore solutions through environmental information technology (EIT) based waste management.

Environmental information technology (EIT)-based waste management is proposed as a solution due to its theoretical and practical advantages. Theoretically, this technology enables data optimization, more accurate monitoring, and more effective planning. Practically, information technology can enhance operational efficiency, reduce costs,

and increase public participation. A more detailed explanation of these theoretical and practical advantages is provided below.

The theoretical advantages of environmental information technology (EIT), ranging from its definition, objectives, utilization, functions, roles, types, and various applications, are systematically explained as follows:

Environmental information technology (EIT) is defined as the application of information technology to manage, process, obtain, organize, store, and manipulate data related to environmental conditions [9]. It is used to provide information to users and support decision-making in environmental conservation efforts [10]. In the context of waste management, EIT refers to a system that utilizes hardware and software to collect, manage, and analyze waste data. The information generated from this system serves as a foundation for better decisionmaking regarding the planning, implementation, and evaluation of waste management.

The primary objectives of utilizing environmental information technology in waste management are to optimize processes, enhance information access, and foster active public participation. Technically, this technology enables more efficient data management, smoother communication among stakeholders, and more informed decision-making. Digital platforms play a crucial role in disseminating information rapidly, increasing transparency, and promoting innovation in waste management [9, 10]. In essence, information technology in waste management aims to streamline communication, improve operational efficiency, and support more informed decision-making at all stages of waste management. Digital platforms facilitate timely and accurate information access.

The utilization of information technology in waste management has become indispensable in addressing the increasingly complex challenges of waste management. Information technology plays a crucial role in enhancing the efficiency, effectiveness, and sustainability of waste management. Technology enables more accurate and rapid collection, analysis, and management of waste data. Additionally, technology can facilitate communication and collaboration among stakeholders, raise public awareness, and support better decision-making [9, 10, 11]. The utilization of such environmental information technology can be understood as the application of information systems in waste management to provide information to customers about waste management in a timely, accurate, effective, and efficient manner, thereby contributing to improved learning processes, increased awareness, and enhanced capacity in utilizing information technology.

The functions of environmental information technology in waste management include serving as a customer service tool and as a data management tool for waste managers [12]. The implementation of information technology in waste management involves various technical components, such as software and hardware, to support data processing [13]. From these descriptions, it can be understood that environmental information technology provides significant functions for both waste managers and customers. Information technology enables more efficient data management and provides real-time information access for customers regarding waste management services.

The role of environmental information technology in waste management includes: enhancing public awareness and communication in waste management [14]. The application of technology in waste management allows for the expansion of service coverage, efficient resource utilization, effective asset management, and regular monitoring of environmental quality. Environmental information technology has become an indispensable tool in addressing the challenges of waste management. Through the development and application of technology, it is expected to build a smarter, more efficient, and sustainable waste management system, thereby contributing to environmental conservation and improving quality of life.

There are six types of information technology used in waste management, namely: computers, networks, software, information systems, programming languages, and databases [10]. Computers and software work together to process data into useful information. Computer networks, especially the client-server model, enable data sharing and interaction between managers and users in the waste management system. Information systems combine various components such as procedures, data, people, and technology to effectively and securely manage waste data. Programming languages are used to create software that controls this system, while databases store and manage waste data in an organized manner.

The types of environmental information technology applications for waste management are diverse and tailored to specific needs and benefits. Several information technology applications used in waste management can be mobile and Android-based [7]. Mobile-based applications are designed to address household waste accumulation problems. This system is designed to facilitate waste management through features such as adding user, courier, and waste type data. The usage stages include: The workflow of a mobile waste management application program involves several stages as depicted in the use case diagram and activity diagram. Android-based applications in waste management follow a system development model that includes system/information engineering and modeling, software requirements analysis, design, coding, testing/verification, and maintenance [15].

"The practical advantages of environmental information technology-based waste management are supported by several previous studies, including: A study on the use of an Android-based application called "Sampah Ta" to increase public participation in waste management in Rappocini District [16]. A digital information system to support waste management programs through social media and blogs has been very helpful in providing the public with faster and more efficient access to information related to TPS3R [17].

To ensure the effective and efficient implementation of environmental information technology-based waste management, it is necessary to support it with an Importance Performance Analysis (IPA) approach. The IPA approach is used due to its theoretical and practical advantages.

Its theoretical advantages can be seen from its definition, usefulness, and strengths, as explained below:

The definition of IPA is a strategic tool used to evaluate the alignment between customer expectations (importance) and the actual performance of a product, service, or organization [18]. The benefits of IPA are: identifying areas for improvement, making

better decisions, increasing customer satisfaction, increasing customer loyalty, and strengthening competitive position. The advantages of IPA are: focusing on priorities, increasing customer satisfaction, objective evaluation, developing long-term strategies.

The practical advantages of the IPA approach in waste management are derived from several previous studies. The mismatch between public perception and the performance of waste collection services, especially regarding the cleanliness of personnel, is a common finding. This result highlights the importance of balancing the fulfillment of public expectations with ensuring efficient operations (pamungkas). Modern technologies, such as advanced software, alternative transportation, modern communication, and sensors, have the potential to improve the efficiency of waste management and reduce waste [8].

Based on the aforementioned background, a study on environmental information technology-based waste management using the Importance Performance Analysis approach is necessary. The objective of this research is to describe and analyze environmental information technology-based waste management at the Sukoharjo landfill in Pati Regency.

It is expected that this research will contribute both theoretically and practically to the Environmental Agency, landfill operators, the community, nongovernmental organizations, students, and environmental researchers.

2 Research Method

This research is an evaluative study aimed at measuring the performance of waste management against established standards. The research method used is a combination of qualitative and quantitative approaches. This study combines primary and secondary data to obtain a more comprehensive understanding of the research object. Primary data includes: interviews, observations, and questionnaires. Secondary data includes: documents, reports, and literature reviews. The research instruments used in this study include questionnaires, observation sheets, in-depth interviews, and document analysis. These instruments were specifically chosen to measure environmental information technology-based waste management. The instruments were tested for validity and reliability. The sampling technique used Proportional Random Sampling and Purposive Sampling. Data analysis in this study combines qualitative and quantitative approaches. Qualitative analysis is used to describe the conditions of the Sukoharjo landfill in depth, while quantitative analysis is used to measure and compare these conditions to established standards. The quantitative method used is Importance Performance Analysis (IPA).

The primary data required for this study includes interviews, observations, and questionnaires. Interviews will gather insights and experiences from landfill managers, stakeholders (local government, community, and private sectors), and the surrounding community regarding the effectiveness of waste management and the application of technology. Observations will focus on the physical conditions of the Sukoharjo landfill, including its facilities, infrastructure, and waste management processes such as col-

lection, transportation, sorting, and treatment, as well as the implementation of information technology in its operations. Questionnaires will assess community satisfaction with waste management services, their expectations for technology-based waste management, and the performance of various aspects of waste management, including reduction, processing, transportation, and closure.

The secondary data includes official documents, reports, and literature reviews. Official documents will provide regulations or policies on waste management, such as laws or local regulations, as well as the standard operating procedures (SOPs) for waste management at the Sukoharjo landfill. Reports will consist of annual performance reports from the landfill, statistical data on waste generation, processing, and transportation, as well as previous evaluations or audits of waste management in the region. Literature reviews will draw on previous studies on technology-based waste management, case studies of successful implementations in other areas, and theoretical frameworks, including the Importance Performance Analysis (IPA) method and qualitative-quantitative approaches.

3 Results and Discussion

3.1 Waste Management at Sukoharjo Landfill, Margorejo Subdistrict, Pati Regency

Waste management at the Sukoharjo landfill in Margorejo Subdistrict, Pati Regency, has been managed according to management functions, including planning, organizing, implementing, monitoring, evaluating, and following up. Planning encompasses: vision, mission, and objectives, resource planning, policy programs, methods, strategies, and procedures, financing, and time schedules. Organization involves relevant parties/institutions such as the Environmental Agency (DLH), Trade and Industry Agency (DISDAGPERIN), Public Works and Spatial Planning Agency (DPUTR), environmental NGOs, and the community. Operational activities of waste management include socialization, waste reduction, containerization, collection, processing/sorting, transfer/transportation, unloading, leveling and compaction, and covering waste with clay. Monitoring includes both internal and external aspects. Evaluation and follow-up are conducted to assess the implementation and non-implementation of waste management according to the standard operating procedures (SOPs) at the Sukoharjo landfill**.**

3.2 Environmental Information Technology-Based Waste Management at Sukoharjo Landfill with an Importance Performance Analysis Approach Results of the descriptive analysis of waste management at Sukoharjo Landfill

The results of the waste management questionnaire survey conducted in Sukoharjo using the Importance Performance Analysis (IPA) approach are as follows

Table 1. Summary of Questionnaire Results on Waste Management Indicators at Sukoharjo Landfill

No.	Indicator	Performance			Importance		
		∑	Mean	%	∑	Mean	%
A.	Waste management plan	1321	4,40	88,07%	1402	4,67	93,46%
B	Organization of waste management	1275	4,25	85,07%	1427	4,757	95,13%
C.	Implementation of waste management activities	5193	4,32	86,55%	5551	4,63	92,51%
D.	Monitoring of waste management	396	3,96	79,20%	459	4,59	87,2%
E.	Evaluation of waste management	442	4,42	88,40%	469	4,69	93,8%
	Sum	8627	4,27	86,27	9308	4,67	92,85%

Based on a survey, the overall waste management at TPA Sukoharjo Pati is considered very good, with an average performance score of 4.27 and an average expectation score of 4.67. All performance indicators, such as planning, organizing, and implementation, obtained an average score above 4, indicating a very high performance. This suggests that waste management at TPA Sukoharjo has been carried out very well according to the established plan. In addition, the community has very high expectations for waste management, with an average expectation score of 4.67. This indicates an alignment between the achieved performance and community expectations.

3.3 Evaluation of a TIL Based Waste Management Matrix in Sukoharjo

An assessment of waste management at TPA Sukoharjo, Margorejo District, Pati Regency, utilizing the IPA approach, revealed that the service provided aligns closely with customer expectations and perceptions. Descriptive analysis indicates a mean performance score of 4.27, signifying a very high level of performance (86.27%), while customers expressed extremely high expectations with a mean score of 4.67 (92.85%). A gap analysis revealed that, for most aspects, performance exceeded expectations. However, there was a negative gap in the sorting and processing of waste based on its physical, chemical, and biological properties. A t-test confirmed a significant difference between perceived performance and expectations ($t = 7.169$, $p < 0.05$). The IPA matrix indicated that the primary focus for improvement lies in the organization and implementation of waste management activities. Conversely, aspects such as planning, implementation, and evaluation, which are highly valued by customers, should be maintained due to their strong performance. Supervision was identified as an area where both customer satisfaction and managerial attention are relatively low. Finally, while customers placed a lower priority on planning and implementation for sorting, processing, and bin adequacy, the service provided in these areas was deemed satisfactory.

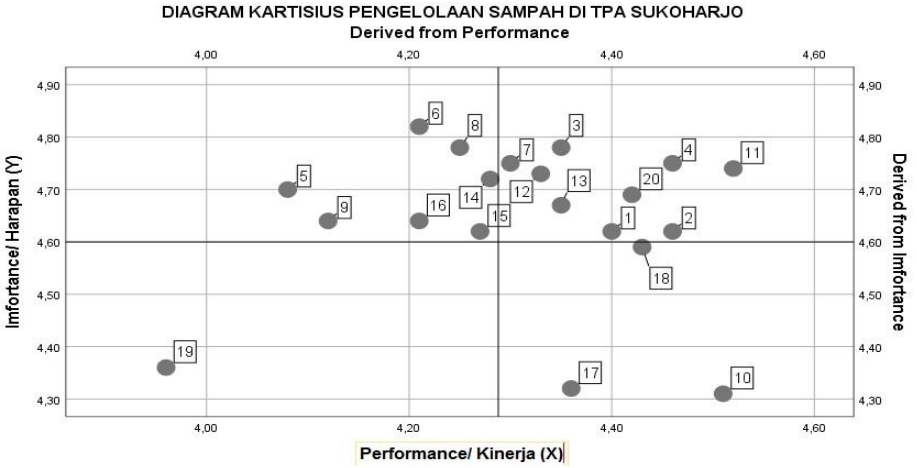

Fig. 1. Kartisus Diagram of Waste Management at TPA Sukoharjo

Based on the diagram above, Quadrant I indicates a significant gap between customer expectations and actual performance in waste management. Low community involvement, lack of synergy among stakeholders, and weak sustainable waste management practices are the main constraints. Quadrant II analysis shows a very high level of customer satisfaction with TPA Sukoharjo. This indicates that the achieved performance indicators, particularly in planning, implementation, and evaluation, are highly effective. To maintain this achievement and continue improving the quality of service, continuous efforts are needed to optimize the performance of TPA Sukoharjo. In Quadrant III, customers are less satisfied with the performance of waste management supervision, but TPA Sukoharjo management does not need to maintain the performance of this supervision. In Quadrant IV, customers are satisfied with the service performance provided by the waste management, starting from the aspects of sorting, processing, and adequate waste bin requirements.

3.4 Descriptive results of TIL-based waste management at TPA Sukoharjo

Table 2. Summary of Questionnaire Results on TIL-Based Waste Management Indicators in Sukoharjo Landfill

No.	Indicator	Performance			Importance		
		∑	Mean	%	∑	Mean	%
A.	The importance of environmental information technology	851	4,26	85,10%	900	4,5	90,00%
B	The purpose of IT in environmental management	1235	4,12	82,33%	1305	4,35	87,00%

No.	Indicator	Performance			Importance		
		∑	Mean	%	∑	Mean	%
C.	The benefits of environmental information technology	1149	3,83	76,60%	1288	4,29	85,87%
D.	The functions of environmental information technology	1222	4,07	81,466 %	1326	4,42	88,40%
E.	The role of environmental information technology	1103	3,68	73,53%	1311	4,37	87,40%
F.	Types of information technology used in data management	1702	4,255	85,10%	1746	4,365	87,30%
G.	Applications of environmental information technology	781	3,905	78,10%	837	4,18	83,70%
	Sum	8043	4,02	80,43%	8713	4,35	87,13%

Based on the evaluation results, the implementation of environmental information technology (EIT) in waste management at Sukoharjo Landfill has achieved a very high level of performance overall. All evaluated indicators, ranging from relevance, objectives, to EIT applications, obtained an average score above the very high threshold, indicating a significant contribution of EIT in optimizing waste management. This is evidenced by the average performance of 4.02 with a percentage of 80.43 in the very good category, while the average expectation obtained an average score of 4.35 with a percentage of 87.13% in the very good category.

3.5 Environmental Information Technology (EIT)-Based Waste Management Matrix at Sukoharjo Landfill

The TIL-based waste management at Sukoharjo Landfill, Margorejo District, Pati Regency, has met customer performance and expectations. This is evident from the results of the descriptive analysis, where the average performance score was 4.02 with a percentage of 80.03% in the very high category, while the importance score was 4.35 with a percentage of 87.13% also in the very high category. The gap analysis showed a positive gap, indicating that the performance of TIL-based waste management was in line with customer performance and expectations. The t-test resulted in a calculated t-value of 4.315, which is greater than the tabulated t-value of 1.658. This supports the hypothesis that there is a significant difference between the performance and expectations of TIL-based waste management at Sukoharjo Landfill. The IPA matrix of waste management showed that the primary improvement focus is in quadrant I: improving the performance of creating a flowchart for waste management, from processing to final disposal, with the aim of facilitating services to customers. In quadrant II, indicators such as the importance of environmental information technology, objectives, benefits, functions, roles, types, and applications of environmental information technology and its

aspects need to be maintained as their service performance is very satisfactory and has met expectations. In quadrant III, the indicator of TIL's function as a tool to simplify and accelerate waste management is considered low by customers, but the Sukoharjo Landfill management does not need to maintain this function of TIL. In quadrant IV, indicators considered not very important by customers but with satisfactory service include the objectives, benefits, types of information technology used in data management, and applications of environmental information technology. A detailed presentation is provided as follows.

The Cartesian Diagram of TIL-Based Waste Management at Sukoharjo Landfill, Margorejo, Pati is depicted as follows:

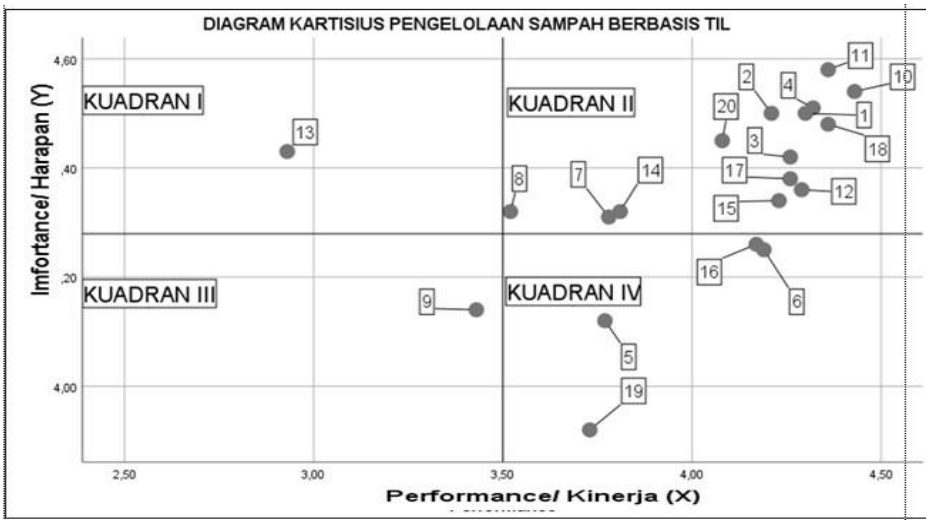

Fig. 2. Cartesian Diagram of TIL-Based Waste Management at Sukoharjo Landfill.

Based on the diagram above, quadrant I indicates that Sukoharjo Landfill needs to optimize its TIL-based waste management system by focusing on developing a comprehensive flowchart. This aims to improve the efficiency of each process stage, from initial processing to final disposal, in order to provide better services to the community. In quadrant II, customer satisfaction with the services provided by Sukoharjo Landfill is very high. This indicates that all aspects of environmental information technology-based waste management, from planning to implementation, have met customer expectations. Therefore, Sukoharjo Landfill needs to maintain, and even improve, the performance that has been achieved. Quadrant III shows customer dissatisfaction with the performance of TIL's function in supporting service efficiency. Customers perceive that the function of TIL in simplifying and accelerating services is not yet optimal. Quadrant IV indicates a high level of customer satisfaction with the achievement of environmental information technology (TIL) objectives at Sukoharjo Landfill. Customers are satisfied with the benefits of TIL, especially in terms of the utilization of certain types of

information technology for data management and the application of relevant TIL applications

4 Conclusion

Based on the research findings presented earlier, it can be concluded that: (1) Waste management at Sukoharjo Landfill has been conducted in accordance with good management principles. The stages of planning, organizing, implementing, monitoring, and evaluating have been integrated to ensure the effectiveness of waste management; (2) The overall performance of waste management at Sukoharjo Landfill is very good, with an average performance score of 4.27 and a percentage of 86.27% in the very high category, while expectations have an average score of 4.67 and a percentage of 92.85% in the very high category. This indicates that customers are very satisfied with the services provided. However, the analysis also shows a gap in terms of waste sorting and processing; (3) waste management at Sukoharjo Landfill based on TIL with Importance Performance Analysis (IPA) has contributed significantly to improving waste management performance, as evidenced by an average score of 4.02 with a percentage of 80.03% in the very high category, while expectations have an average score of 4.35 with a percentage of 87.13% in the very high category, thus meeting customer expectations. Nevertheless, the IPA analysis identifies several areas that need improvement, especially related to the creation of a waste management flowchart. These findings have important implications for the development of TIL-based waste management systems in the future. The waste management based on Environmental Information Technology (EIT) at the Sukoharjo Landfill has achieved high performance, improving access to information, management efficiency, and customer satisfaction. The analysis indicates that the priority for improvement lies in the development of a waste management flowchart, while satisfactory technological indicators need to be maintained. EIT has proven to be effective in supporting high-quality management and services.

Suggestions. Based on the research findings, it is recommended that the Pati Regency Government, particularly the Department of Environment (DLH), develop policies for waste management and increase public participation as well as support from relevant stakeholders to achieve more effective and efficient waste management through the utilization of environmental information technology.

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