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UNDERGRADUATE THESIS

**STRATEGIC PLANNING OF SUSTAINABLE
ELECTRONIC WASTE MANAGEMENT PROCESSING
FACILITY (*FPSS*) THROUGH SYSTEM DYNAMIC
MODEL AND GIS IN TEMBALANG, BANYUMANIK,
AND SEMARANG UTARA SUB-DISTRICT**



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 Model and GIS In Tembalang,
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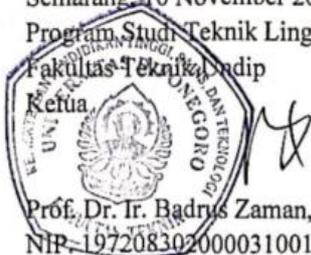


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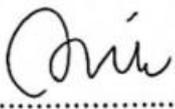
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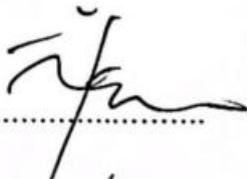

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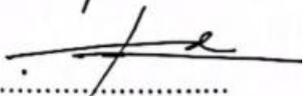
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ABSTRACT

This research addresses the escalating challenge of electronic waste (e-waste) management in Semarang City, Indonesia, amid rapid global electronification and population growth. E-waste, classified as hazardous under Government Regulation No. 9 of 2024, has surged to 62 billion kg worldwide in 2022, with only 22.3% formally recycled, posing severe environmental and health risks from improper disposal. In Indonesia, households contribute 49.5% of hazardous waste, with Semarang generating 1,110 tons of daily household waste, including significant e-waste from sub-districts Tembalang (14.1%), Banyumanik (28.2%), and Semarang Utara (7.1%). These areas, characterized by high population density, educational hubs, commercial zones, and industrial activities, lack integrated systems, relying predominantly on informal collectors who employ unsafe practices like open burning and acid immersion. The study aims to develop a strategic plan for a Sustainable Electronic Waste Management Processing Facility (FPSS) in these sub-districts. It analyzes existing conditions, including community disposal behaviors, e-waste generation rates (e.g., 0.102 liters/person/day residential), and current management deficiencies. Projections from 2025 to 2045 incorporate population growth, economic factors, and informal sector roles, evaluating impacts across five aspects: organizational, funding, legal, community participation, and technical operations. Employing a System Dynamic Model (SDM) via Powersim software to simulate e-waste flows and feedback loops, alongside Geographic Information System (GIS) for hotspot mapping and facility siting, the research proposes integrated mechanisms for collection, transportation, and sorting. Outputs include CAD drawings, SketchUp models, planned area maps, and cost budgets. Benefits encompass enhanced policy formulation for government, reduced pollution and health hazards for communities, and professional development for the researcher, fostering sustainable e-waste recovery valued at 2.2-14 billion USD nationally.

Keyword: Electronic waste (e-waste); Hazardous waste; Waste management; System Dynamic Model (SDM); Geographic Information System (GIS); Sustainable facility (FPSS).

CHAPTER I

INTRODUCTION

1.1 Background Research

Electronification has been the fastest transformation worldwide over the last 15 years. The increase in electronic device ownership has been massive, along with a surge in the interconnectivity of regions connected to the Internet. Different types of technological products continue to evolve in terms of models and technology applications. The demand for electronic products will continue to rise alongside the population growth rate, which is also increasing and the fact that people frequently replace their devices (Raharjo & Utomo, 2021). This rapid advancement has significant implications, leading to a rise in waste generated by electrical and electronic devices (e-waste), which is currently among the fastest-growing categories of solid waste globally, increasing at a rate of about 5% annually, which is three times quicker than traditional household waste (Baldé et al., 2024).

According to the United Nations University (2018), electronic waste refers to electronic devices that are no longer used, damaged, or cannot be repaired, including a wide variety of small household appliances such as blenders, hair dryers, and toasters, large household appliances such as refrigerators and washing machines, and IT and telecommunications devices such as computers, laptops, and printers. The growth rate of e-waste is increasingly concerning, with the volume of e-waste in 2022 increasing five times faster than in 2010. This high growth rate of e-waste has not been matched by adequate collection and recycling. The Global E-waste Monitor reports that in 2022, the total global e-waste generated reached 62 billion kg of e-waste, or an average of 7.8 kg per capita. of this amount, only 22.3% or 13.8 billion kg of electronic waste was successfully collected and formally recycled. The majority of the remainder is not properly documented and poses potential environmental pollution and health risks (Baldé et al., 2024).

At the national level, the Directorate General of Waste, Waste and Hazardous Materials Management (Ditjen PSLB3) under the Ministry of Environment and Forestry (KLHK) reported that electronic waste production in Indonesia reached 2

million tons in 2021 (Ditjen PSLB3, 2021). Households are a major contributor to hazardous and toxic waste (B3) in the country, accounting for 49.5% of waste in 2023 (SIPSN, 2024). However, many people are unaware that certain household items become Hazardous and Toxic Waste after use. These items, which include electronic and electrical waste contain chemicals that can react dangerously (Achmad Gunawan Widjaksono & Lingkungan Hidup Dan Kehutanan, 2022).

According to Government Regulation No. 9 of 2024 regarding the Management of Specific Waste, electronic categorized as B3 specific waste. The management were handled differently depending on its source. Electronic waste from service sectors like business, commercial or plant governed by stricter regulations with the Law No. 32 of 2009 on Environmental Protection and Management and Government Regulation No. 101 of 2014 on B3 Waste Management, are legally responsible for their own waste management, requiring them to use a temporary facility and work with licensed third-party waste management companies for disposal. Meanwhile, the responsibility for managing specific waste produced in residential areas falls to the local city or regency government (KLHK, 2024).

Despite this regulatory framework, electronic waste management in many developing countries, including Indonesia, is still dominated by the informal sector. More than 60% of e-waste in Indonesia is processed by the informal sector, with the remainder being directly disposed of in landfills without treatment and without regard for environmental impacts or health risks (Adrian et al., 2020; Syafrudin et al., 2023). Electronic waste collected and purchased by informal workers door-to-door from households and public institutions is then resold, refurbished, or dismantled to retrieve valuable components (Achmad Gunawan Widjaksono & Lingkungan Hidup Dan Kehutanan, 2022). This dismantling process often occurs without proper safety measures, involving practices like acid immersion and open burning of cables and plastics (Ramadan et al., 2023). Such methods release harmful substances, including dioxins, furans, and strong acids, which pose lethal risks (Mairizal, Sembada, Tse, & Rhamdhani, 2021). Furthermore, the financial gains are not equitably shared, with informal workers at the lower end of the value chain receiving minimal compensation compared to the profits made by formal

recycling companies (International Labour, 2014). The remainder disposal of electronic waste into landfills causes hazardous substances to leach into soil, contaminating surrounding land (Adu & Aneke, 2025). These heavy metals can infiltrate groundwater, contaminating drinking water for communities, animals, and plants, even miles from the disposal site. Studies show e-waste significantly increases mortality rates among children near these dumps (Lovo & Rawlings, 2024).

Most electronic waste that lacks immediate resale value ends up as residue, leading to the loss of valuable resources that could otherwise be reclaimed. Electronic waste is rich in high-value metals like gold (au), silver (ag), copper (Cu), platinum (Pt), and palladium (Pd), which are considered critical raw materials (CRMs). The potential for recovering these valuable materials from underutilized e-waste could amount to 7-8 billion kg (Baldé et al., 2024) with an estimated economic worth in Indonesia ranging from 2.2 to 14 billion USD, as a result, electronic waste is the most valuable type of solid waste for recycling compared to other waste categories (Xavier, Ottoni, & Abreu, 2023). The recovery rates of e-waste are highly influenced by the amount of electronic waste entering the processing system and the efficiency of collection and dismantling systems (Baldé et al., 2024). While Indonesia's National Action Plan for 2020-2025 outlines provisions for e-waste collection facilities, local implementation faces significant challenges. In Semarang, for instance, inadequate information dissemination, unappealing bin designs, and suboptimal placement have hindered the utilization of provided infrastructure (Rimantho, Syaiful, Nurfaida, & Sulandari, 2022). There is a discrepancy between national regulations or policies and implementation at the regional level underscores a broader issue: the lack of integration between collection and processing systems. Furthermore, Indonesia grapples with insufficient infrastructure and policies to support the informal sector's role in e-waste management (International Labour, 2014).

Given these circumstances, a multidisciplinary strategy is essential to connect technical, environmental, and socioeconomic factors to enhance the sustainable e-waste management. This gap between national policy and local execution

underscores a broader issue: the lack of integration between collection and processing systems. Furthermore, Indonesia grapples with insufficient infrastructure and policies to support the informal sector's role in e-waste management. Previous research, such as Paminto, Lautetu, Prayoga, and Debora (2024) has conducted descriptive analyses of e-waste management in Indonesia, emphasizing the need for specific regulations and stakeholder participation. Through a case study in Yogyakarta, Rochman, Ashton, and Wiharjo (2017) mapped e-waste flows and revealed the informal sector's dominance in collection and sorting, despite profits concentrating at upper hierarchy levels, suggesting informal sector incorporation into management frameworks. Meanwhile, andarani and Goto (2012) examined the economic feasibility of setting up a household e-waste processing facility in Serang, showing that the business is financially viable but requires additional support and a well-designed collection system to ensure the sustainability of material supply. Raharjo and Utomo (2021) conducted a comparative analysis of e-waste management between developed countries and Indonesia, recommending 4R program adoption and informal sector collaboration. Furthermore, Ahirwar and Tripathi (2021) offer a comprehensive review of global e-waste management, addressing environmental and health risks from improper recycling, and propose strategies for more efficient and safe recycling. Overall, the existing literature suggests that the primary challenges in e-waste management in Indonesia are the lack of specific regulations, insufficient formal infrastructure, and the significant role of the informal sector, which has not been optimally integrated, despite the promising potential for economic value recovery from e-waste. The aforementioned research identifies a gap in the technical review of e-waste management, specifically in the analysis of dynamic systems and the application of Geographic Information Systems (GIS) for facility mapping. This gap serves as a critical foundation for conducting a more comprehensive technical review.

This final project will be conducted in Semarang City, the capital of Central Java Province with 16 sub-district in total and covers an area of 373,78 km² with a total population of 1,708,833 people as of 2024 one of the most populous urban centers (BPS, 2025). This city generates 1,110 tons household waste per day, with

specific types of hazardous and toxic waste (B3) are still mixed with other waste. According to Yudha Widanto (2021) in residential and office sectors in Semarang City, waste generation sampling showed approximately 0.102 liters per person per day for residential waste and 0.027 liters per employee per day for office waste. A primary driver of this e-waste generation is the demographic composition of the city. Currently, there is no integrated e-waste management system in place. This research will focus on three key sub-districts: Tembalang, Banyumanik, and Semarang Utara due to their high population density and diverse urban characteristics, which result in significant e-waste production, coupled with suboptimal management practices. Tembalang is a major educational and residential with a population of approximately 145,991, primarily consisting of students. This demographic is associated with a high turnover of personal electronic devices like smartphones and laptops, making it a key source of consumer e-waste. Banyumanik, with a population of around 145,370, contributes to a diverse e-waste stream from its mix of residential neighborhoods and commercial areas. This includes not only personal electronics but also a variety of commercial equipment. Finally, Semarang Utara stands out as a critical area due to its dense concentration of industries and a diverse population. The varied residential population adds to the general consumer e-waste. According to reports generated by the Semarang Environmental Agency (2024), indicates that Banyumanik contributes 28.2% of e-waste, Tembalang 14.1%, and Semarang Utara 7.1%, making them the areas with the most significant e-waste contributions in the city. Currently, e-waste collection is predominantly managed by informal collectors (*pengepul*), without proper sorting, dismantling, or hazardous material treatment, and no formal facilities exist to manage e-waste before disposal or recycling. The combined e-waste from these three populous and distinct districts highlights the multifaceted challenge of managing electronic waste in Semarang (BPS, 2025). The implementation in the three sub-districts of Semarang City serves as a benchmark or practical implication for other regions within the city.

The objective of this final project is to develop a strategic plan for a Sustainable Electronic Waste Management and Processing Facility (FPSS) in Three sub-

districts, namely Semarang Utara, Banyumanik, and Tembalang. This will be achieved through an analysis utilizing a System Dynamic Model (SDM) and hotspot spatial mapping via Geographic Information System (GIS). The System Dynamic Model, developed using Powersim software, is employed to simulate and visualize the complexity of e-waste flow and to predict the systemic impacts of various management scenarios over time. This modeling approach facilitates a dynamic representation of feedback loops and time delays inherent in e-waste systems (Dasgupta et al., 2017). SDM has been used to predict e-waste generation and the distribution of disposal percentages through various channels such as landfills, second-hand markets, and recycling, to inform better management practices in the future. SDM can handle complex systems involving many variables and interdependent factors. This enables analysis of the relationship between consumption per capita, GDP per capita, and electronic device obsolescence rate (Deva & Weijden, 2021). Additionally, spatial analysis using GIS supports in identifying the distribution of e-waste generation points and potential collection sites, integrates various data operations, analyzes, stores, and displays them in the form of maps based, thereby supporting the determination of strategic locations for facility placement (Putranto, Hezim, Citrasari, & Santoso, 2019). The combination of human resources and GIS will provide a comprehensive understanding of the e-waste system, from predicting generation to evaluating policy impacts, thereby supporting accurate decision-making for sustainable FPSS planning. This integrated approach will help formulate a management strategy that integrates the roles of the government, community, collectors, and recycling facilities.

1.2 Problem Identification

Based on the stated background, the identified problems of this final project are as written below.

1. According to Government Regulation No. 9 of 2024, household electronic waste is classified as hazardous waste under government management. However, Indonesia's current system for handling electronic waste lacks integration and coordination, especially in establishing a well-organized collection network and thereby decreasing recovery rates and polluting the environment

2. In Tembalang, Banyumanik and Semarang Utara Sub-districts, Semarang City, a comprehensive and environmentally sound e-waste management system has not yet been established. although there are action plans and some collection efforts, the utilization of existing infrastructure remains minimal, resulting in uncontrolled accumulation and unregulated disposal of electronic waste.

3. There is no systematic mapping of the existing e-waste conditions in Tembalang, Banyumanik and Semarang Utara Sub-districts, Semarang City that connects key factors through a System Dynamics Modeling (SDM) approach and spatial mapping using a Geographic Information System (GIS) to understand the dynamics of e-waste flows and formulate comprehensive management strategies.

4. Tembalang, Banyumanik and Semarang Utara Sub-districts, Semarang City currently lacks facilities for Sustainable E-Waste Management Processing Facility (FPSS), which poses a major challenge in achieving sustainable e-waste control in the region.

1.3 Problem Conceptualization

1. How is the existing condition of electronic waste (e-waste) in Tembalang, Banyumanik and Semarang Utara Sub-districts, Semarang City, including the behavior patterns of the community in disposing of e-waste, the amount of electronic waste generated, and the current waste management system in the area?

2. How is the potential for e-waste generation and its impact on e-waste management along with its 5 aspects in Tembalang, Banyumanik and Semarang Utara Sub-districts, Semarang City?

3. How are the plan of an Electronic Waste Management Processing Facility (FPSS) suitable for Tembalang, Banyumanik and Semarang Utara Sub-districts, Semarang City, including integrated mechanism for collection, transportation, and sorting of e-waste, to support sustainable electronic waste management.

1.4 Goals Conceptualization

1. Analyzing the existing condition of electronic waste (e-waste) in Tembalang, Banyumanik and Semarang Utara Sub-districts, Semarang City, including the

behavior patterns of the community in disposing of e-waste, the amount of electronic waste generated, and the current waste management system in the area.

2. Analyzing the potential for future e-waste generation and the impacts of electronic waste management that covers the 5 aspects in Tembalang, Banyumanik and Semarang Utara Sub-districts, Semarang City.

3. Planning an Electronic Waste Management Processing Facility (FPSS) suitable for Tembalang, Banyumanik and Semarang Utara Sub-districts, Semarang City, including integrated mechanism for collection, transportation, and sorting of e-waste, to support sustainable electronic waste management.

1.5 Problem Limitation

Problem limitation is done to focus on a certain scope of the planning and does not stray from the original plan. Therefore, the problem limitations for this planning are:

1. This thesis focuses on planning an e-waste management processing facility (FPSS) and analyzing the existing condition of e-waste generated by households in three sub-districts, namely Tembalang, Banyumanik & Semarang Utara in Semarang City.

2. This plan will take into account projections for population growth, electronic waste. production, and the role of the informal sector from 2025 to 2045.

3. Electronic waste management planning which includes 5 waste management aspects (Organizational/Institution, Funding, Laws and Regulations, Community Participation, and Technicality operation) would be based on prior evaluation of existing waste management conditions in Semarang City.

4. Planning of Electronic Waste Management Processing Facility (*FPSS*) from collection to sorting & classification with the output of CAD drawings, Sketchup, planned area maps, and Cost Budget Plans.

5. Collection of primary and secondary data will be sourced from Semarang City.

1.6 Benefit

The benefits of this plannings are as follows

1. For the author/Planner

- To expand knowledge, insight, skills, character, and profession ability through an implemented study by planning and developing an Electronic Waste Management Processing Facility (FPSS)
- Allows the author to implement concepts and theories gained from academic studies into practical planning
- To fulfill the Final Project course requirements in the Environmental Engineering Study Program, Faculty of Engineering, Universitas Diponegoro, and graduation requirements for the Environmental Engineering Study Program.

2. For The Government

This plan can provide direct benefits to the government as a basis for consideration in designing a more effective and contextual electronic waste management system, particularly in the city of Semarang. The results of the analysis and planning can be used to optimize the collection, transportation, and sorting of e-waste, as well as support the development of integrated waste treatment infrastructure. as a result, the government can formulate more targeted policies, address electronic waste management issues, and improve environmental quality in a sustainable manner.

3. For the People of Semarang City

- Educating the community on the significance of managing electronic waste in a safe and eco-friendly manner
- Establishing organized systems or channels for e-waste disposal to guide the community on where and how to discard their old electronic gadgets responsibly
- Minimizing the risk of environmental contamination and health hazards resulting from careless e-waste disposal
- Encouraging job opportunities in the areas of e-waste collection, sorting, and processing
- Contributing to the development of cleaner, healthier, and more pleasant living spaces.

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