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UNDERGRADUATE THESIS

**The Planning of Organic Waste Treatment Through
Renewable Energy Transformation Using Heat Value
And Dynamic Model In Kudus Regency**



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Telah berhasil dipertahankan di hadapan Tim Penguji dan diterima sebagai bagian persyaratan yang diperlukan untuk memperoleh gelar Sarjana pada Departemen Teknik Lingkungan, Fakultas Teknik, Universitas Diponegoro.

Pembimbing I:

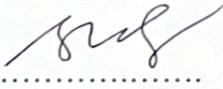
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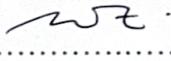
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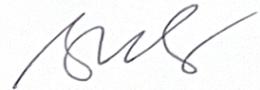
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ABSTRACT

Waste has become an emerging environmental issues, especially in urban areas, rapid population growth and high consumption patterns tend to contribute to an increasing volume of waste each year. This study highlights concerns about the rising amount of wet organic waste in urban areas, especially in Kota Kudus and Jati Sub-Districts of Kudus Regency. The temporary closure of the Tanjungrejo landfill was a turning point that revealed the fragility of the current waste treatment system. The planning study presents a fresh solution to these issues through anaerobic digester waste processing technology which transforms wet household organic waste into renewable energy. The planning process for this waste treatment facility uses baseline data from population growth projections and estimates of domestic waste generation in Kota Kudus and Jati Sub-Districts, Kudus Regency, until 2044. The design results are presented in the form of two-dimensional (2D) and three-dimensional (3D) visual outputs for the TPST facility, with a dynamic modeling scheme using Powersim software that converts energy from organic waste, focusing on the conversion of methane production into electrical energy using the Heat Value Method. Based on projections and planning. From the 217.06 m³/day of waste entering the integrated waste treatment facility, 17.33 m³/day of organic waste will be treated through an anaerobic treatment system using two active domes and two backup domes. Meanwhile, other types of waste such as inorganic waste transported by the offtaker. Then, through a dynamic modeling scheme, it will be further developed to produce 4,753.15 kWh/day of electrical energy. In addition, this plan also includes a construction cost budget estimate of IDR 7,113,739,800.89 and total revenue up to Rp4,929,591,621.25 a year. This study also prepared with a comprehensive project management planning using MS Project software.

Keyword : Integrated Waste Processing Facility, Anaerobic Digester, System Dynamic Model.

CHAPTER I INTRODUCTION

1.1 Background Research

Indonesia has the 4th largest population in the world with a total population of 270.20 million based on the 2020 population census (Wance et al., 2025). The large population is certainly in line with the large amount of waste generated in Indonesia. Waste has become a persistent environmental challenge, especially in urban areas where rapid population growth and consumption patterns contribute to increasing waste volume each year (Salsabila et al., 2021). According to the Ministry of Environment report in 2024, Indonesia's total waste generation touched 33,541,026.18 tons/year with total 63.22% is an organic waste. Waste treatment infrastructure that is still not balanced with the amount of waste generation makes around 69% of waste generated by the community end up in landfills, 7% of waste is processed through recycling, and the remaining 24% is only disposed of without being processed (KLHK, 2024). The landfill method commonly used in Indonesia is open dumping, where the use of this method results in negative impacts in the form of liquid/leachate that has the potential to pollute groundwater and surface water, the production of methane gas (CH₄) and carbon dioxide (CO₂) (I. Priyambada & Oktiawan, 2020).

According on data from the National Waste Management Information System (SIPSN), waste generation in Central Java in 2023 was recorded at 40,202,161.24 tonnes/year, an increase of 14.03% from the previous year (KLHK, 2023). Over the past five years, Central Java has been the province with the highest waste generation in Indonesia (Kholiq et al., 2025). Kudus Regency is one of the eastern districts of Central Java Province, covering a total area of 425.15 km² and divided into 9 sub-districts, 9 urban villages, and 123 rural villages (BPS, 2024). Kudus is also recognized as one of the regencies in Central Java that serves as a major center of economic growth with a strong industrial base. As a “home for many industries,” Kudus hosts several large-scale companies operating across

various sectors, including printing, tobacco, and manufacturing (Setiawan & Yusuf, 2025). The intensity of industrial activities, combined with a growing population, has contributed to a significant increase in waste generation. In 2022, the waste generation in Kudus Regency reached 163,578.95 tonnes per year, with organic waste accounting for 29% of the total. Approximately 35.04% of unmanaged waste is burned, landfilled, or disposed of improperly, leading to environmental pollution in water, soil, and air. The lack of waste reduction efforts has increased the amount of waste entering landfills, accelerating the filling of landfill capacity (BAPEDA, 2025). SIPSN for 2023 also reported, the majority of waste in Kudus Regency originates from the domestic sector, accounting for 54.5% of the total waste generated. This is followed by waste from markets (20.8%), public spaces (7.1%), commerce (6.0%), offices (3.4%), and other sources (4.8%). In terms of composition, the data show that food waste represents the single largest fraction, reaching 24.9%, followed closely by wood and branches (23.5%) and paper/carton (18%). Other notable categories include plastic (12.6%), fabric (4.4%), glass (4.2%), rubber (3.6%), and metals (0.6%) (KLHK, 2023). The dominance of waste from the domestic sector and the composition of food waste indicate a strong influence of household consumption patterns on the overall waste stream in Kudus Regency (KLHK, 2023).

In terms of waste management, Kudus classifies municipal solid waste into three main categories to facilitate more efficient processing: inorganic waste, dry organic waste, and wet organic waste. This categorization allows direct involvement from industrial off-takers. For instance, inorganic waste is managed and utilized by Industry X through Refuse-Derived Fuel (RDF) technology, while dry organic waste such as branches and leaves is processed by Industry Y through composting. However, wet organic waste especially food residues remains a major challenge due to its dominant volume and the complexity of its treatment process. In addition, the infrastructure and management systems for solid waste processing in Kudus Regency are still inadequate to manage the generation of ever-increasing waste (Prasetia et al., 2020). Based on the reports from Tempo (2025), the lack of

these facilities resulted in the forced closure of Tanjungrejo Landfill (*TPA Tanjungrejo*), which is the main and the only final disposal site in Kudus Regency, between January 16th and 25th, 2025. Such protests occurred due to lack of waste management facilities, lack of restraint on the waste which is piling, lack of control of putrid smells, and other repetitive and persistent over environmental impacts which demonstrates the lack of sustainability of prevailing waste management. Temporary closure of Tanjungrejo Landfill not only halted the waste collection and disposal system in Kudus Regency, but also rendered the lack of comprehensive and systematic approaches to the solution of municipal solid waste management.

From this perspective, Jati Sub-district and Kota Kudus Sub-district were chosen as the research areas for a number of academic and practical considerations. These two sub-districts illustrate the urban and peri urban center of Kudus Regency, with high population density, high commercial activities, and considerable waste being produced on a daily basis (Sari & Mardiansjah, 2025). Being the focal points of socio-economic activities, both areas generate a great deal of integrated municipal waste, thereby providing a basis for investigating the relationships among waste generation, collection, disposal, and management in the context of Kudus Regency (Ariani et al., 2023). Additionally, the selection of Kota Kudus Subdistrict and Jati Subdistrict allows for spatial analysis of differences in domestic solid waste management practices among urban settlements, businesses, and public institutions. As a final point, it is also important for the policies, planning, and waste management of the region that the facilities and the administrative center of the Kudus are also located in these sub-districts.

On the other hand, dependence on increasingly limited fossil fuels and their impact on climate change has prompted efforts to develop more environmentally friendly alternative energy sources. Fossil fuels sustain global energy needs, and also lead to more than 75% of carbon dioxide (CO₂) emissions (Canton, 2021). Excess consumption of oil, natural gas, and coal have drained the Earth's atmosphere (Yang et al., 2022). Fossil fuels contain hydrocarbons, which release greenhouse gases, including CH₄ and CO₂, depleting dust layer capabilities to trap

UV radiation from the sun (Shahbaz et al., 2020). Other harmful gases such as CO and SO₂ contribute to acid rain (Wu et al., 2020). The extraction of fossil fuels has endangered the ecological balance in some areas. Additionally, coal mining has claimed the lives of many miners. For these reasons, in recent years, many developed and developing countries have increasingly focused on the use of renewable energy (solar, wind, geothermal, biomass, etc.) to diversify energy resource use, reduce dependence on fossil fuels, and maintain environmental balance (Azadi & Karimi-Jashni, 2016).

One of the applicable methods for processing organic waste and converting it into renewable energy is the anaerobic digesting system. An anaerobic digester is a technology that utilizes anaerobic microorganisms to break down organic materials in an oxygen-free environment, with the aid of high concentrations of organic compounds (Singh et al., 2019). The anaerobic digestion process typically emits strong odors due to the presence of gases such as hydrogen sulfide (H₂S), ammonia (NH₃), and other volatile compounds (I. B. Priyambada & Wardana, 2018). This process produces biogas, which generally contains 50–70% methane (CH₄) and 30–40% carbon dioxide (CO₂) (Schnürer & Jarvis, 2018). Refined biogas, or biomethane, is a superior form of biogas with broader and more efficient applications as an environmentally friendly renewable energy source. As such, biogas has the potential to serve as a sustainable energy solution for both heat and electricity generation (Kabeyi & Olanrewaju, 2022). Biogas plays a vital role in supporting the achievement of the Sustainable Development Goals (SDGs), as it is a widely available energy resource across communities and nations (Belinska et al., 2023). Most notably, it contributes to SDG 7 (Affordable and Clean Energy) by providing renewable and decentralized energy sources that reduce dependence on fossil fuels. At the same time, biogas supports SDG 13 (Climate Action) by mitigating greenhouse gas emissions, particularly methane, that would otherwise be released from unmanaged landfills. Now is the time to explore the possibilities of Waste to Energy (WTE) both as an alternative for solid waste management as well as a significant economically viable and environmentally sustainable

renewable energy source for the future (Bajić et al., 2015; A. Kumar & Samadder, 2017; Roy et al., 2022).(Bajić et al., 2015; A. Kumar & Samadder, 2017; Roy et al., 2022).

In waste-to-energy systems, accurately assessing the heating value of organic waste captured as Higher Heating Value (HHV) and Lower Heating Value (LHV) is critical for optimizing thermal conversion processes such as combustion, gasification, and anaerobic digestion (Dong et al., 2022). HHV represents the total energy released from complete combustion, including the latent heat of water evaporation, while LHV reflects the net energy available for conversion into electricity or heat (Baziar et al., 2025). In the context of biogas, this method calculates the amount of energy that can be generated from the CH₄ methane from biogas process formed. This heating value is generally expressed in megajoules per cubic meter (MJ/m³) or British Thermal Units (BTU) and serves as the basis for determining how much energy can be converted into electricity (kWh).

Modeling plays an important role in the planning of domestic waste treatment systems by providing a structured and systematic approach that enables the simulation of complex dynamics in the context of waste management, thereby allowing for a comprehensive evaluation of various alternatives before implementation (Alam & Ahmad, 2015). One of the most widely adopted approaches in this context is the System Dynamics Model, which is particularly effective in capturing the intricate and interconnected nature of waste generation and treatment processes. This research employs system dynamics modeling using Powersim software to examine the potential of organic waste conversion into renewable energy. By simulating the energy conversion from the waste treatment system, the study aims to provide meaningful insights into the transformation of organic waste into bioenergy, including estimations of electricity production for household lighting and the broader potential for energy distribution.

In conclusion, the challenges of waste management in Kudus Regency, which are the recent shutdown of Tanjungrejo Landfill, driven by overcapacity and environmental concerns, underscores the pressing demand for innovative and

sustainable solutions. Focusing on Jati Sub-district and Kota Kudus Sub-district as, this undergraduate thesis discusses issues related to organic waste, particularly wet household organic waste, using anaerobic digester treatment and exploring its transformation into renewable energy. Through the integration of Heat Value methods and System Dynamic modelling, it further pursues to provide a future framework for calculating effective calorific values and modelling the potential for transforming organic waste into renewable energy. Ultimately, this approach not only supports waste management by local governments, but is also in line with broader global commitments to sustainable development and the transition to renewable energy.

1.2 Problem Identification

Based on the research background provided and existing condition survey in the research area, the identified problems of this undergraduate thesis are as detailed below

1. Kudus Regency produced 163,578.59 tons of waste in 2022, with organic waste accounting for 29% of the total. However, 35.04% of the waste is unmanaged either landfilled, mismanaged, or disposed of improperly, leading to significant environmental risks.
2. The infrastructure and management of solid waste in Kudus Regency remain inadequate to cope with the continuously increasing volume of waste. According to Tempo, one of Indonesia's largest media outlets, these issues culminated in the forced closure of Tanjungrejo Landfill (*TPA Tanjungrejo*), the main final disposal site in Kudus Regency, by local residents from January 16 until 25, 2025. The protest escalated due to overcapacity and uncontrolled waste accumulation, unpleasant odors, and other recurring environmental impacts.
3. The 3R-based Waste Collection Facility (*TPS 3R*) and Integrated Waste Processing Facility (*TPST*) facilities are not operating effectively in accordance with their designated functions. As a result, the volume of waste

directly transported to the Tanjungrejo landfill continues to increase, thereby intensifying the daily burden on the site.

4. The majority of the community in Kudus Regency particularly in the study areas of Jati Sub-district and Kota Kudus Sub-district as well as relevant stakeholders still hold a misconception that waste management is limited merely to transporting waste to transfer stations (*TPS*) or final disposal sites (*TPA*). The lack of education and public outreach has resulted in low levels of waste segregation, reduction, and recycling (3R) practices
5. Indonesia, including Kudus Regency still relies heavily on fossil fuels (coal, oil, gas) for energy, which contributes to more than 75% of CO₂ emissions.

1.3 Problems Statement

Based on the identified problems, the conceptualization of the issue can be outlined as follows:

1. How are the existing conditions of domestic waste in Kota Kudus and Jati Sub-districts, Kudus Regency, including its generation, characteristics, and current management practices?
2. How to model the potential of renewable energy production from the anaerobic digestion process using a System Dynamics model and the Heat Value method?
3. How the planning of infrastructure of the Integrated Waste Treatment Facilities through anaerobic digestion?

1.4 Goals Conceptualization

The goals of planning domestic solid waste management operational techniques can be described as follows:

1. Analyzing the existing conditions of waste generation, waste characteristics, and current treatment practices.
2. Developing a Dynamic Model for renewable energy production from organic waste treatment through anaerobic digestion process using the Heat Value Method.

3. Planning waste processing facilities, including design specifications and a draft cost budget.

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. The scope of this study covers an analysis of the planning area, which includes a review of general regional conditions, waste generation and composition, and the current municipal solid waste management practices in Kudus Regency.
2. The planning process takes into consideration the projected population growth and estimated domestic waste generation in Kota Kudus and Jati Sub-district, Kudus Regency, up to the year 2044.
3. The selected waste treatment technology in this study is anaerobic digestion, which is specifically designed to handle wet organic waste that currently lacks adequate treatment.
4. A System Dynamics model is employed to simulate the production of renewable energy from organic waste, focusing on the conversion of heat energy into electrical energy through the Heat Value Method.
5. The design of the waste treatment facility will include outputs in the form of 2D and 3D visualizations, regional planning maps, budget plans, and project management.

1.6 Benefits Conceptualization

The expected benefits of planning Integrated Waste Processing Facility (*TPST*) and developing renewable energy transformation using anaerobic digestion through System Dynamic Model and Heat Value Method in Kota Kudus and Jati Sub-districts are as follows:

1. For the Author/Planner

- a. To enhance the author's knowledge, insight, technical skills, character, and professional competence through the planning and development of an *TPST*;
- b. To provide the opportunity to apply theoretical concepts and methodologies acquired during academic studies into a practical, real-world planning project;
- c. To fulfill the requirements of the undergraduate thesis proposal course in the Environmental Engineering Study Program, Faculty of Engineering, Universitas Diponegoro, as well as to meet the graduation requirements of the program.

2. For Science

This research contributes valuable insights and recommendations regarding waste management planning and treatment. It utilizes the Heat Value Method and System Dynamics Modeling as methodological tools to support decision-making in waste processing strategies.

3. For Government and Policy Makers

The outcomes of this study can serve as a reference for local governments and relevant agencies in formulating effective waste management plans. Specifically, it provides a basis for the development of *TPST* in Kota Kudus and Jati Sub-districts, aiming to address and improve current waste handling issues in those areas.

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