Innovative Strategies and Technologies in Waste Management in the Modern Era Integration of Sustainable Principles, Resource Efficiency, and Environmental Impact

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Abstract

In the context of waste management in the modern era, environmental challenges are increasingly complex. Innovative strategies and sustainable technology are important to answer this problem. This study aims to analyze the environmental impact of implementing innovative strategies and technologies in waste management and to provide recommendations for mitigating negative impacts. The literature study method is used to collect and analyze relevant data. The results of this research illustrate the positive potential of innovative strategies in waste management but also emphasize the need for careful mitigation measures to reduce negative impacts on the environment. In facing the challenges of waste management, innovative strategies, and technologies provide real opportunities to achieve environmental sustainability in the future.

Keywords: *Innovative Strategy, Waste Management, Sustainability Principles, Resource Efficiency, Environment.*

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A. INTRODUCTION

Waste management has become a central issue in this modern era, where population growth and rapid urbanization have caused an increase in the volume of waste produced. Improper collection, treatment, and disposal of waste can harm the environment and human health. Effective and sustainable waste management is becoming increasingly important to meet this challenge. Garbage, especially non-biodegradable waste, can contaminate soil, water, and air (Khan et al., 2022). Hazardous chemicals in waste can damage natural ecosystems and threaten human health. As consumption and disposal of goods continue to increase, it is important to develop management strategies that can reduce these negative impacts. A sustainable approach to waste management is important because it combines economic, social, and environmental aspects. This strategy aims to optimize long-term benefits while considering resource efficiency and environmental impact (Silva et al., 2021).

Efficient waste management in the use of important resources to reduce waste and optimize the value of waste. Innovative technologies can play a role in identifying new ways to recycle, convert, or convert waste into new resources. Technological

developments provide new opportunities in waste management (Maiurova et al., 2022). From smart sensors for waste monitoring to advanced processing techniques, technology can help optimize the entire waste management chain. It is important to integrate innovative technologies with sustainable principles in waste management. This includes designing systems that minimize environmental impact, promote recycling, and ensure community participation (Sharma et al., 2021).

Successful waste management does not only rely on technology but also involves active community participation. Awareness of the importance of proper waste management and environmentally friendly practices needs to be increased. Good waste management can provide economic benefits through the recovery of valuable materials, the creation of jobs, and the reduction of waste processing costs. It also contributes to the formation of a sustainable economy. Waste management issues are complex, involving many stakeholders such as government, industry, and society. A holistic approach is needed that takes these diverse aspects into account (Lihua et al., 2020).

This research aims to analyze innovative strategies and technologies in waste management in the modern era. By integrating the principles of sustainability and resource efficiency, this study aims to provide an in-depth look at how new approaches can lead to more sustainable and efficient waste management while minimizing adverse environmental impacts.

B. LITERATURE REVIEW

1. Waste management

According to Azwar, waste is something that is no longer used, that cannot be used again, that is not liked, and must be thrown away, so waste must of course be managed as well as possible, in such a way, that things that are negative for life do not happen. Kodoatie defines waste as solid or semi-solid waste or waste, which is a by-product of urban activities or the life cycle of humans, animals, and plants (Pandebesie et al., 2019).

The many waste problems around us require proper handling so as not to cause new problems. According to the Republic of Indonesia law number 18 of 2008 concerning waste management, it states that waste management is a systematic, comprehensive, and sustainable activity that includes reducing and handling waste. With waste management, environmental pollution due to waste accumulation can be resolved properly (Andriani & Atmaja, 2019).

Wahyono, Edy Hendras, and Nano Sudarno argue that waste management consists of several stages, including:

a. The stage of collection and storage at the location of the waste source, namely the temporary waste storage area. These wastes are distinguished based on their type in different places, namely organic waste (wet waste) and inorganic waste (dry waste). The waste from household activities can be collected at the depot (garbage house) (Hoang et al., 2022).

b. The Transportation Stage, namely the collection of waste from the temporary waste storage site or depot (garbage house) to be taken to the final disposal site (TPA) (Mawaddah & Putra, 2022).
c. Extermination Stage. There are several methods used in the waste disposal stage, namely:
    1). Sanitary landfill, namely a system of destroying waste by piling up waste with soil which is done layer by layer, so that the waste is not in open space and does not smell.
    2). Incineration, is a method of destroying waste by burning waste on a large scale using factory facilities.
    3). Composing, namely the method of destroying waste by decomposing organic matter by decomposing germs under certain conditions.
    4). Hog Feeding, providing wet waste to livestock. An example is pork. Before being given garbage, it must be processed first to prevent transmission of helminthiasis and trichinosis.
    5). Discharge to Sewers, is a way to destroy waste by pulverizing it and then putting it into the wastewater disposal system. This method depends on whether the wastewater disposal system is good or not.
    6). Dumping, waste is left just like that in the fields, ravines, or trash cans (Dharmaraj et al., 2021).

However, this method feels less effective and efficient, so an integrated waste management system is needed. Integrated management is the selection made starting from the source, both from households, markets, industry, schools, public facilities, and other sources. Stages of integrated waste management include:

a. Waste sorting, namely separating organic waste from inorganic waste.
b. Recycling, this activity can be carried out at the waste source or taken to a waste recycling place. Organic waste is usually composted and inorganic waste is transported to the recycling industry. The rest or residue from the process can be piled up using the sanitary landfill method (Mir et al., 2021).

2. Sustainable Principles

The concept of sustainable development better known as sustainable development is a process of development (land, cities, businesses, communities, and so on) that has the principle of "meeting the needs of the present without compromising meeting the needs of future generations". One of the factors that must be faced to achieve sustainable development is how to repair environmental destruction without compromising the need for economic development and social justice. "Environment" is where we all live, while "development" is what we all do to improve and enhance human destiny (Tsalis et al., 2020).

According to the Ministry of Environment, sustainable development can be measured based on 3 (three) criteria, namely: There is no wastage of natural resources; No pollution and other environmental impacts; and Activities must be able to increase useable resources or replaceable resources. Sustainable development with an

environmental perspective requires solid integration and coordination between the utilization of natural resources, human resources, and man-made resources within a certain time frame, and spatial dimension, and coordinated so that they are effective, effective, and efficient (Yahman & Setyagama, 2022). This principle has been realized since the environmental conference in Stockholm in 1972, where one of the points of the declaration stated: "That in the context of a more rational management of resources to improve the quality of the environment, an integrated and coordinated approach was decided in planning for sustainable development with an environmental perspective" (Hjorth & Madani, 2023).

In Indonesia, the definition of the concept of sustainable development has progressed. The official definition of the concept of sustainable development is contained in Law Number 32 of 2009 concerning Environmental Protection and Management. This law is a renewal of Law Number 23 of 1997 concerning Environmental Management. In Law Number 32 of 2009, Article 1 paragraph 3 Sustainable development is defined as follows. Sustainable development is a conscious and planned effort that combines environmental, social, and economic aspects into development strategies to ensure the integrity of the environment as well as the safety, capabilities, welfare, and quality of life of present and future generations (Tong et al., 2021).

In the previous Law Number 23 of 1997, the definition of sustainable development is somewhat different, namely: Sustainable development with an environmental perspective is a conscious and planned effort, that integrates the environment, including resources, into the development process to guarantee capability, welfare, and quality of life of present and future generations (Karjoko et al., 2022).

Environmental Protection and Management Act, Law no. 32 of 2009 is expected to have a positive impact on environmental governance in Indonesia and is in line with sustainable development. One of the strategic issues in Law No. 32 of 2009 requires the creation of KLHS (Strategic Environmental Studies), for the preparation and evaluation of Regional Spatial Planning along with detailed plans, for the Provincial and Regency/City levels. On the other hand, Law No. 32 of 2009, is intended to increase the concern, awareness, and responsibility of stakeholders (policymakers, implementers, and communities affected by development) so that they realize the importance of environmental protection and management (Hadi et al., 2023).

3. Resource Efficiency

Resources are any elements or components of the environment that can be used to carry out activities that result in production activities. Resources can be grouped as natural resources and human resources. Natural resources are environmental elements consisting of biological and non-biological resources which as a whole form a unified ecosystem. Based on their nature, natural resources can be divided into renewable resources, for example, water, air, and plants; and non-renewable resources, such as petroleum, coal, and other mining (Usman et al., 2022).

Efficiency is a measure of the level of utilization of resources in a process. The more efficient / less utilization of resources, the process is said to be more efficient. Efficiency is the minimum utilization of resources to achieve optimum results. Efficiency assumes that the right goals have been determined and tries to find the best ways to achieve these goals (Kuang et al., 2020). The concept of efficiency is fundamental and was born from the concept of economics. Nevertheless, the concept of efficiency can be defined from various perspectives and backgrounds. In general, efficiency can be directed to the concept of achieving a result with optimal utilization of resources (Abubakr et al., 2020).

According to S. P. Hasibuan, the concept of efficiency is the best comparison between input and output (the result of profits and resources used). The best results are achieved using limited resources. It also means the relationship between what has been completed. Meanwhile, according to Mulyama, efficiency is a measure of comparing a plan for using input or using input with actual use or actual use (Nguyen et al., 2020).

Efficiency generally has various types. Here are some types of efficiency:

a. Optimum Efficiency

   Optimal efficiency is the best comparison between the sacrifices made to get a desired result. In terms of results, an example of optimal efficiency is when a manager can achieve an output (productivity, performance) that is higher than the input (labor, money, time, and materials) used. Meanwhile, in terms of savings, an example of optimal efficiency is the use of modern equipment so that the work process will be faster and will save time and costs (Matos et al., 2021).

b. Efficiency by Benchmarking

   The efficiency with a benchmark is a comparison between the specified minimum result and the actual result achieved, which can be said to be efficient if the real result is greater than the specified minimum number. For example, worker A can lay about 200 bricks per day for 8 hours. Meanwhile, worker B can lay around 300 bricks per day for 8 hours. The benchmark is the worker's ability to achieve predetermined results within a certain time (Bouwer et al., 2023).

c. Efficiency with Break-Even Point

   Efficiency with a break-even point is often used in business fields where the break-even point is the boundary point between efficient and inefficient business. A business can be said to be efficient if its break-even point is known and the business produces more than that break-even point (Chanysheva & Ilinova, 2021).

Efficiency can certainly be found in all areas of human life. In general, efficiency goals are as follows:

a. Achieve a result or goal as expected or planned.
b. Save or also reduce the use of resources in carrying out activities or activities.
c. Maximize the use of all available resources so that nothing is wasted.

d. Improving the performance of a work unit so that the result or output is maximized.
e. Maximizing possible profits (Hickel, 2019).

It can be said that the goal of efficiency is to achieve maximum profit with minimal effort also called optimal efficiency. Optimal efficiency is the best comparison between the sacrifices made to get an expected result (Costanza, 2020).

4. Environment

Otto Soemarwoto believes that the environment is all the objects and conditions that exist in the space we occupy and influence our lives. According to Otto Soemarwoto, the definition or scope of the definition of the environment is broad, not only covering the earth and everything in it but also covering outer space. The definition of the living environment is the unity of space with all objects, forces, conditions, and living creatures, including humans, and their behavior, which influence the continuity of life and welfare of humans and other living creatures and can influence their lives (Adawiah, 2019).

The definition of the environment can be said to be everything around humans or living creatures that have a reciprocal and complex relationship and mutual influence between one component and other components. A deeper understanding of the environment according to Article 1 point 1 of Law Number 32 of 2009 concerning Environmental Protection and Management is as follows: "The environment is a spatial unity with all objects, forces, conditions, and living creatures, including humans and their behavior, which affects nature itself, the continuity of life, and the welfare of humans and other living creatures" (Mazzocchi, 2020).

The living environment as referred to in the law is a system that includes the living natural environment, the non-living natural environment, the built environment, and the social environment. All components of the environment such as objects, forces, conditions, and living things gather in one container which is the gathering place for these components, which is called space (Pizza & Kelemen, 2023). In this space, an ecosystem takes place, namely an arrangement of living organisms in which harmonious and stable interactions are established between the abiotic environment and these organisms, giving and receiving life. The interactions between these various components are sometimes positive and often negative. A positive situation can occur if there are circumstances that encourage and help the smooth running of environmental life processes (Assadi-Langroudi et al., 2022).

Negative interactions occur when the process of harmonious environmental interaction is disrupted so that the interaction goes against each other. Any disturbance to one component in the environment will harm other components because the balance of these components is no longer harmonious (Grier et al., 2022).

In these two elements, there is a reciprocal relationship, they influence each other and are dependent on each other. One living creature has a reciprocal relationship with other living creatures and with inanimate objects around it. The existence of a reciprocal relationship between living things and their environment

indicates an interaction between living things and the environment in which they live or live. Living creatures influence the environment, and conversely, changes in the environment will affect the lifestyle of the living creatures living in it (Usami et al., 2019).

C. METHOD

To dig deeper insights into strategies and innovative technologies in waste management in the modern era, this research will be carried out through a qualitative approach using the literature study method. This research will use data that comes from various research results and previous studies that are relevant to related issues, as well as combine information obtained from the background of the problems that have been described previously. By utilizing research data that has been collected, this research will conduct in-depth analysis to produce a more comprehensive understanding of innovative strategies in waste management, integration of sustainable principles, resource efficiency, and expected environmental impacts.

D. RESULT AND DISCUSSION

1. Innovative Strategy in Sustainable Waste Management

Sustainable and efficient waste management requires innovative approaches at various stages of the process, from collection to final disposal. One of the emerging new strategies is technology-based smart collection. Through sensors and internet technology, waste collection efficiency can be increased by scheduling based on actual waste volume. In addition, revolutionary treatment methods such as pyrolysis can convert organic waste into energy or high-value products, reducing the environmental impact of conventional waste treatment. An approach to reducing waste at source is also important, by stimulating society to produce less waste by reducing the consumption of single-use plastics or through eco-friendly product designs.

Innovative strategies in waste management offer several advantages that have the potential to overcome the constraints of conventional waste management. Smart collection scheduling reduces the time and cost required for empty waste collection. Pyrolysis and other revolutionary processing methods allow the conversion of waste into alternative energy sources, reducing dependence on fossil fuels. The continuation of this strategy can also increase community participation in waste management because they see real environmental and economic benefits. Strategies to reduce waste at source can lead to greater behavior change in the long term, by educating people about the negative impacts of excess waste.

These new types of strategies can be applied in a variety of geographical and social contexts. Sensor and internet technology can be adapted according to the needs and infrastructure of each region. Revolutionary processing methods such as pyrolysis can be optimized according to local resource availability. Reducing waste at source can be adjusted according to culture and the level of public awareness of environmental issues. Although innovative strategies offer great potential, there are

still some challenges that need to be overcome. New technologies may require high initial investments, although the long-term impact can offset this. The introduction of new methods also requires changes in regulations and policies, as well as public education. However, if these challenges can be overcome, innovative strategies have the potential to be widely adopted and contribute significantly to sustainable and efficient global waste management.

As an illustration, several regions have successfully implemented this innovative strategy. For example, a city has introduced a smart collection system that has succeeded in reducing the frequency of empty waste hauling and optimizing routes. A waste processing plant uses the pyrolysis method to produce energy from organic waste, reducing the volume of waste sent to landfills. A local community has adopted a waste reduction approach at source through an educational campaign that has successfully reduced the use of single-use plastics.

The implementation of innovative strategies is expected to have a significant long-term impact. By reducing the amount of waste that goes to landfill and using more efficient technology, this strategy can reduce environmental impacts such as water and land pollution. In addition, reducing dependence on fossil fuels through waste processing can reduce greenhouse gas emissions, supporting climate change mitigation efforts. Ultimately, the findings of innovative strategies in waste management show great potential in creating a more sustainable and efficient system. Smart collection, revolutionary treatment, and reduced waste at source can all provide significant benefits for the environment, society, and the economy. Even though the challenges still exist, adopting innovative strategies is an important step in facing the challenges of waste management in the future.

2. Sustainable Principles in Waste Management Strategy

Sustainable principles play a crucial role in designing and implementing effective and sustainable waste management strategies. Among these principles is recycling, which encourages minimizing waste by reusing existing materials. Waste reduction is also important, by curbing waste production at the source through reducing consumption and use of single-use products. Utilization of renewable resources includes the use of renewable energy in waste processing, reducing the impact of using fossil fuels. Community participation is a fundamental principle in sustainable waste management, inviting the community to play an active role in waste sorting and management.

The principles of sustainability are integrated in various stages of the waste management strategy. In planning, the strategy focuses on designing systems that enable recycling and reduction of waste at source. In the implementation stage, an educational program is implemented to increase community participation in proper waste segregation and management. The use of technology can also support the use of renewable resources, such as solar or wind energy to process waste. Continuous evaluation of the strategy will ensure that sustainable principles are continuously addressed and improved.

Implementation of sustainable principles in waste management strategies has far-reaching long-term impacts. Socially, involving the community in waste management can increase environmental awareness and social responsibility. This can also open up employment opportunities in the recycling and waste processing industry. Economically, adopting renewable energy in waste processing can reduce energy costs and generate income from the sale of the energy produced. The environmental impact is also significant, with reduced volumes of waste going to landfills and reduced fossil fuel emissions.

An example of implementing sustainable principles in waste management is the implementation of a recycling program that actively involves the community. Through education and separate collection facilities, this program has succeeded in reducing the amount of waste that ends up going to landfills. In waste processing, the integration of renewable energy such as biogas from organic waste has increased efficiency and reduced environmental impacts. In implementing sustainable principles, synergy between the government, industry, and community sectors is key. The government needs to create regulations that support sustainable waste management and provide incentives for industries that adopt environmentally friendly practices. Challenges also exist, such as varying public awareness, or difficulties in adopting renewable technologies in certain conditions.

It can be concluded that the integration of sustainable principles in waste management strategy brings great potential in creating a more sustainable, efficient, and environmentally friendly system. Recycling, reducing waste, utilizing renewable resources, and community participation form the basis for designing successful strategies. The implementation of these principles in the planning, implementation, and evaluation of strategies will produce positive long-term impacts in social, economic, and environmental aspects. Although challenges exist, collaboration and commitment from various stakeholders can ensure success in dealing with complex waste management challenges.

3. Resource Efficiency Through Innovative Technology

Innovative technologies have changed the paradigm of waste management, bringing more efficient and sustainable solutions. One example is automatic separation, where sensor technology and data processing are used to separate different types of waste automatically. Energy recovery technology utilizes waste to produce electrical or heat energy, such as through pyrolysis or gasification processes. Advanced processing technologies such as aerobic and anaerobic composting also speed up the process of decomposing organic waste. Innovative technology helps optimize the use of resources in waste management. Recovery of valuable materials from waste, such as metals and plastics, through automated separation technologies, can reduce the need for new raw materials. Processing organic waste through anaerobic methods can produce biogas, a renewable energy source that can reduce dependence on conventional energy sources. Utilization of energy produced from organic waste also helps optimize resource potential.

One of the main goals of innovative technology in waste management is to reduce the wastage of resources. Automatic separation helps ensure that materials that still have economic value are not wasted. Energy recovery technologies turn waste that was previously considered useless into a valuable source of energy. By processing organic waste into valuable materials or energy, innovative technology helps reduce waste that must be disposed of in landfills. The use of innovative technology in waste management has the potential to generate positive environmental impacts. Reducing the need for new raw materials through the recovery of valuable materials reduces the impact of new mining and production. Utilization of renewable energy from organic waste reduces fossil fuel emissions. In addition, innovative technology helps reduce the volume of waste that ends up in landfills, reducing the impact of land and water pollution.

While innovative technologies offer great potential, there are challenges in their widespread adoption. Some technologies may require high initial investment, while technical and operational aspects also need attention. In addition, acceptance by the public and other stakeholders can also be a challenge, especially if changes in the waste management process are perceived as major changes. Resource efficiency through innovative technology is an important step in creating more sustainable and efficient waste management. Automatic separation technologies, energy recovery, and advanced processing technologies bring more effective solutions for minimizing waste and utilizing existing resources. Optimization of resource use and reduction of waste contribute to the reduction of negative environmental impacts. Although challenges exist, the application of innovative technology has great potential to overcome obstacles in conventional waste management and support change toward a more sustainable waste management system.

4. The Environmental Impact Of Implementing Innovative Strategies And Technologies

In implementing innovative strategies and technologies in waste management, it is very important to evaluate the environmental impacts that may occur. Greenhouse gas emissions, such as methane produced from decomposing organic waste, can influence climate change. Water pollution may also occur due to the percolation of water through piles of rubbish, bringing harmful substances into water sources. In addition, changes in waste management systems can result in damage to natural habitats, especially if landfills are located in ecologically sensitive areas.

The application of innovative strategies and technologies also brings the potential for significant positive benefits for the environment. Reducing plastic waste through sorting and recycling can reduce the risk of marine pollution and damage to marine ecosystems. Reducing greenhouse gas emissions through processes such as pyrolysis or energy recovery from waste can help in climate change mitigation efforts. Utilizing waste as a new resource, such as turning waste into fuel or raw materials for other products, can reduce dependence on natural resources.

To reduce potential negative impacts on the environment, several mitigation efforts need to be implemented. Good planning is an important first step, selecting appropriate locations for landfills and waste processing, and avoiding sensitive ecological areas. Strict supervision during the waste processing and disposal process is important to prevent water and air pollution. Better technology and innovation in waste management can also help reduce environmental impacts, for example by reducing emissions or optimizing recycling processes.

Sustainable waste management requires the integration of appropriate recommendations. Comprehensive planning must consider environmental aspects and identify safe areas for final disposal. More sophisticated technology must be pursued, such as technology that reduces harmful emissions during the processing process. Increasing public awareness and education about the importance of proper waste management is also a crucial step in reducing negative impacts.

The environmental impacts of implementing innovative strategies and technologies in waste management have complex dimensions. Impact evaluation involves considering various aspects, including greenhouse gas emissions, water pollution, and potential habitat damage. However, the potential environmental benefits of using innovative strategies and technologies are significant, including reduced plastic waste, reduced emissions, and the use of waste as a new resource. Mitigation efforts, such as careful planning, close monitoring, and technological development, will help reduce possible negative impacts. In facing current environmental challenges, sustainable and innovative waste management is an important step towards a greener and more sustainable future.

E. CONCLUSION

Waste management in the modern era faces increasingly complex and urgent challenges. Through the implementation of innovative strategies and technologies, it will be possible to respond to these challenges sustainably and efficiently. The environmental impacts of implementing innovative strategies and technologies need to be carefully evaluated, including potential negative impacts such as greenhouse gas emissions, water pollution, and habitat destruction. However, the resulting environmental benefits, such as reducing plastic waste, reducing emissions, and utilizing waste as a new resource, have great potential in overcoming current environmental problems. To maximize benefits and minimize negative impacts, mitigation efforts through good planning, strict supervision, and technological improvements must be the main focus. Public awareness also needs to be increased so that participation in sustainable waste management can run effectively. With the synergy between technological innovation, strategic planning, and active community participation, the future of waste management can bring significant positive changes to the environment, maintain the sustainability of our planet, and create a better environment for future generations.

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