International Journal of Social Science, Educational, Economics, Agriculture Research and Technology (IJSET) | ISSN (e) : 2827-766X
Volumes 4 No. 5 (2025)

AN INTEGRATIVE APPROACH BETWEEN WASTE MATERIAL TECHNOLOGY AND ENVIRONMENTAL IMPACT MITIGATION STRATEGIES

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Received	: 30 March 2025	Published	: 29 April 2025
Revised	: 08 April 2025	DOI	: https://doi.org/10.54443/ijset.v4i5.1030
Accepted	: 24 April 2025	Publish Link	: https://www.ijset.org/index.php/ijset/index

Abstract

Environmental problems due to increased waste demand innovative and sustainable solutions. This study aims to examine an integrative approach between waste material technology and environmental impact mitigation strategies. The method used is descriptive qualitative with a case study approach, through field observations, in-depth interviews, and documentation studies. The results of the study show that the use of waste treatment technology, such as making paving blocks from recycled plastics and fly ash-based geopolymers, is able to significantly reduce the volume of waste and produce products with high use value. Environmental mitigation strategies, such as policy incentives and educational campaigns, have been proven to strengthen the implementation of these technologies. The success of integration is also influenced by multi-stakeholder collaboration involving society, academia, government, and the private sector. This approach not only offers technical solutions, but also creates a sustainable socio-ecological system. Therefore, the integration between waste technology and mitigation strategies needs to be continuously developed as part of efforts to realize sustainable development based on resource efficiency, environmental protection, and community empowerment.

Keywords: ***Waste Technology, Environmental Mitigation, Integrative Approach, Circular Economy, Sustainable Development***

INTRODUCTION

Environmental problems are becoming an increasingly urgent global issue to be addressed immediately (Surasmi et al., 2022). Along with the increase in industrial activities, development, and human consumption, the generation of solid and liquid waste continues to increase significantly. Poorly managed waste not only pollutes the environment, but also threatens human health and the ecosystem as a whole (Asri, 2020). One of the innovative approaches that has begun to be developed to respond to this problem is an integrative approach between waste material technology and environmental impact mitigation strategies. This approach seeks to combine technical solutions with sustainable policies in a single synergistic framework of action (Kusumastuti et al., 2025). In this context, waste is no longer seen as a waste product that must be disposed of, but rather as a potential resource that can be reused. The concept of circular economy emphasizes that waste can be reprocessed into raw materials with high use value (MacArthur, 2013). Waste treatment technology has undergone rapid development in recent decades. Innovations such as fly ash-based geopolymers, artificial aggregates from recycled plastics, and green concrete are real examples of the transformation of waste into highly useful construction materials (Mehta & Monteiro, 2006). However, technological transformation alone is not enough. Integration with environmental mitigation strategies is needed which includes aspects of regulation, regional planning, public education, and the application of low-emission technology. This integrative approach supports the Sustainable Development Goals (SDGs), particularly on points 12 and 13 on responsible consumption and production and action on climate change (Georgeson & Maslin, 2018). Conceptually, an integrative approach requires a synergy between engineering and environmental science. Waste material treatment technology must be designed not only for production efficiency, but also for its impact on the environment throughout the product life cycle (life cycle assessment) (Rasyid, 2023).

Several studies show that the use of waste as a construction material can reduce the carbon footprint by up to 40% compared to conventional materials. For example, the use of steel slag or fly ash as a cement substitute has been shown to reduce CO_2 emissions produced during the construction process (Van Deventer et al., 2012). Environmental impact mitigation strategies generally include three main approaches: preventive, remedial, and adaptation. The preventive approach emphasizes the importance of preventing pollution from the outset through the design of environmentally friendly production systems, while remediation focuses on restoring already contaminated environmental conditions (Rasyid, 2023). Adaptation is very important in the context of climate change that causes environmental uncertainty. Therefore, the use of waste-based technologies that are adaptive to local geographical and climatic conditions is a relevant option to be applied in various regions, especially in developing countries (Sachs, 2015). The integration between technology and environmental strategies requires a transdisciplinary approach (Marsini & Dwikoranto, 2022). This means that not only scientists and technocrats are involved, but also policymakers, the private sector, local communities, and NGOs. This multi-stakeholder participation is an important foundation for the success of technology-based waste management (Scholz & Binder, 2011).

On the other hand, the main challenge of this integrative approach lies in coordination and harmonization between sectors. There is a gap between the development of technology in the laboratory and the implementation on an industrial scale, as well as the unpreparedness of regulations in accommodating new technologies (Azapagic & Perdan, 2011). National and regional environmental policies are often not responsive to waste treatment innovations. In addition, budget limitations and low public awareness are inhibiting factors in the implementation of a sustainable integrative approach (Irfandi, 2024). In fact, the benefits of this approach are not only in the form of pollution reduction, but also economic efficiency. Processed waste products have potential market value, both as alternative building materials, renewable energy sources, and environmentally friendly consumer products (Surasmi et al., 2022). Moreover, the integration of waste technology and mitigation strategies also supports the creation of new jobs in the green economy sector, as well as encourages the emergence of environment-based social enterprises (Sachs, 2015). At the local level, community-based initiatives such as waste banks, eco-bricks, and creative industries of recycling show that these approaches also have a strong social dimension. The success of the integrative approach also depends on changes in people's behavior and consumption patterns. Environmental education and counseling are important components in building collective awareness of the importance of technology-based waste management. High environmental literacy will strengthen public acceptance of recycled products and waste treatment technologies (Sterling & Orr, 2001)

In the academic context, more cross-disciplinary research is still needed evaluating the effectiveness of integrating waste technology with environmental impact mitigation policies. This approach should be tested comprehensively in a variety of social, economic, and geographical contexts (Gibson et al., 2013). This research is important to bridge the gap between technological innovation and socio-economic reality. Without a systemic approach, technological solutions risk causing new negative impacts or social inequality in access to these technologies. Thus, an integrative approach between waste material technology and environmental impact mitigation strategies is not only a technical solution, but also a holistic socio-ecological approach. This demands a paradigm transformation in seeing the relationship between humans, technology, and nature (Marsini, 2023). Based on the description above, this study aims to analyze and formulate an optimal integrative approach in utilizing waste as a technological material, while reducing its negative impact on the environment. With this approach, it is hoped that a real and measurable balance between economic development and ecological sustainability will be achieved.

RESEARCH METHODS

The research method used in this study is qualitative descriptive with a case study approach (Assyakurrohim et al., 2023). This approach was chosen to describe in depth how the integration between waste material treatment technology and environmental impact mitigation strategies is applied in practice, as well as how effective it is in a real-world context. The main focus of this study is to understand the processes, actors involved, and the social-technical dynamics that occur in the implementation of the integrative approach. Data were collected through field observation techniques, in-depth interviews, and documentation studies. Observations were carried out in several waste treatment locations that have applied recycling technology to be used as construction materials or other functional products. Interviews were conducted with various parties, including waste treatment facility managers, local government representatives, environmental communities, and end users of processed waste products. This interview technique is semi-structured to allow the researcher to dig deeper and deeper information from the informant (Miles & Huberman, 1992). In addition, documentation studies are used to examine policies, regulations, and reports related to waste management and environmental mitigation policies. Document sources include government documents, scientific journals, NGO reports, and technical publications from research institutions. The collected data was analyzed thematically, using data reduction, categorization, and conclusion drawing techniques. This process was carried out to find patterns of linkages between the use of waste material technology and environmental mitigation strategies. The validity of the data is maintained through triangulation of sources and methods. By comparing the results of observations, interviews, and documents, researchers try to obtain a complete and reliable picture. In addition, member checks are also carried out on several key informants to ensure that the researchers' interpretations are in accordance with the reality they are experiencing. This research does not aim to produce generalizations, but to enrich the understanding of best practices that can be used as a reference in the development of similar policies and technologies in other areas. Therefore, local, social, and ecological contexts are important considerations in the analysis and interpretation of research results. With this approach, it is hoped that research will be able to make a meaningful contribution to the development of more sustainable waste management and environmental preservation strategies.

RESULTS OF RESEARCH AND DISCUSSION

1. Practice of Utilizing Waste Material Technology in the Field

The results of observations show that several waste treatment facilities in the study area have applied waste treatment technology into alternative construction materials. For example, at one of the treatment sites, plastic waste is collected, sorted, and then processed using a molding machine into paving blocks and light bricks. This process not only reduces the amount of plastic waste that pollutes the environment, but also results in products that are competitive in quality and price. Interviews with the facility manager revealed that they use simple technology based on manual presses and printing machines that have been modified to save energy. The technology is developed locally and adjusted to the socio-economic conditions of the surrounding community. This is in line with the concept of appropriate technology that emphasizes efficiency, affordability, and sustainability (Sterling & Orr, 2001).

The results of the study show that the use of waste material technology directly in the field has shown great potential in supporting the reduction of waste volume, while producing products of economic value. This practice clearly reflects the principles of the circular economy as explained by (MacArthur, 2013), where waste is no longer considered a burden, but rather as a resource that can be reprocessed into a new product. In this context, the processing of plastic waste into paving blocks, as well as the use of fly ash for geopolymers, proves that industrial and domestic waste can be integrated into construction production systems. This phenomenon also strengthens the idea of appropriate technology as expressed by (Böhm et al., 2018), which emphasizes that technology must be adapted to local conditions, both in terms of community capabilities and available resources. The innovation of simple printing machines used at the research site shows that a low-tech approach can be a relevant and sustainable solution in waste management at the local level. In addition to being environmentally friendly, the technology is also easy to adopt by people with basic skills.

2. Environmental Mitigation Strategies That Support Waste Treatment

From the results of the documentation study and interviews with representatives of the regional environmental agency, it was found that the success of the use of waste technology is highly dependent on supportive local policies. Several regions have implemented mitigation strategies in the form of tax incentives for industry players who use recycled materials, as well as public education campaigns on waste sorting and reducing from households. In addition, mitigation efforts also include strengthening regulations on industrial and household waste management, the development of green industrial estates, and the application of the principle of extended producer responsibility (EPR), where producers are required to be responsible for the management of waste from their products. This institutional support is the key to integration between technological innovation and environmental policy. Technology integration cannot be separated from the support of regulations and mitigation strategies implemented by the government. In this case, the findings of the study reveal that regulations such as fiscal incentives, waste sorting campaigns, and EPR policies have strengthened the implementation of waste treatment technology. These findings are in accordance with the theory of environmental impact mitigation put forward by (Rasyid, 2023), which emphasizes the importance of a combination of preventive, remedial, and adaptation approaches as a comprehensive environmental protection strategy. Furthermore, these results also support the ISO 14040:2006 framework on Life Cycle Assessment, where waste treatment technology needs to be analyzed from the entire product life cycle, including environmental and social aspects. A mitigation strategy that favors sustainability will extend the useful life of the recycling technology while minimizing the environmental impact that may arise in the future. This is in line with the Sustainable Development Goals (SDGs), especially in points 12 and 13, which emphasize the importance of sustainable production and action on climate change.

3. Multi-Stakeholder Collaboration in the Implementation of Integrative Approaches

The study found that an integrative approach can only succeed if there is close cooperation between various parties: government, local communities, academics, and business actors. In some locations, there is active collaboration between environmental NGOs and village governments in building community-based waste treatment units. Academics play a role in providing technology assistance and training. Interviews with community leaders show that the success of technology implementation is greatly influenced by the level of citizen participation. The active involvement of the community creates a sense of ownership and responsibility for the sustainability of the system. This is in line with the view (Gibson et al., 2013) about the importance of inclusive governance in the management of natural resources and the environment.

One of the key points found in this study is that cross-sector collaboration is a key factor in the success of the integrative approach. Collaboration between governments, NGOs, academics, and local communities creates a complementary system: technology is provided by academics, policies are driven by the government, training is conducted by NGOs, and communities are the main actors in implementation. This collaborative model reflects a transdisciplinary approach as described by (Scholz & Binder, 2011), which emphasizes the importance of the involvement of all stakeholders in designing and implementing environmental solutions. Community support also reflects the principle of inclusive governance (Gibson et al., 2013), namely governance that involves all actors equally in the decision-making process and implementation of activities. When the community is involved from the beginning, they tend to be more active in maintaining the sustainability of the technology applied. This strengthens the legitimacy and social acceptance of any form of technological intervention, so that the results are not only short-lived but also long-lasting.

4. Comparison of Efficiency and Impact of Waste Material Technology

Table 1 Comparison of the Three Types of Waste Treatment Technology Observed in the Field

Types of Technology	Types of Waste	Product Results	Waste Reduction Efficiency	Operating Costs	Potential for Mitigation of CO_2 Emissions
Plastic Paving Block Printing	Mixed plastics	Paving block	60–70%	Low	Tall
Geopolymer Fly Ash	Fly ash	Eco-friendly lightweight concrete	50–65%	Intermediate	Tall
Household Organic Compost	Organic waste	Compost fertilizer	80–90%	Low	Keep

The data above shows that each technology has its own advantages and challenges. Plastic-waste-based technology excels in the potential for building material substitution and emission reduction, while organic waste treatment is highly effective in reducing domestic waste generation. A comparative analysis of the three types of waste treatment technologies found in the field shows that each technology has its own strengths in terms of efficiency, operational costs, and environmental mitigation potential. Recycled plastic-based technologies make a major contribution to reducing CO_2 emissions and at the same time produce economically competitive products. This is in line with the results of the study (Van Deventer et al., 2012) which shows that the use of fly ash as a cement substitute can significantly reduce carbon emissions. Composting from organic waste, although having a lower emission mitigation impact, is highly effective in reducing household waste generation and improving soil fertility. From a local and social perspective, this technology is particularly relevant for rural communities that are close to the source of organic waste. This proves that the effectiveness of the integrative approach is also greatly influenced by the geographical and socioeconomic context of the people who apply it, as affirmed by the (Sachs, 2015) in the context of adaptation to climate change and sustainability. As such, it is important to understand that no one technology is superior in all aspects. The choice of technology must be adjusted to local conditions, the dominant type of waste, and the capacity of the community. This is where the systemic and holistic approach as expressed becomes particularly relevant: the relationship between humans, nature, and technology is inseparable, and environmental solutions cannot only be technical-based, but must also be socio-ecological.

CONCLUSION

This study shows that an integrative approach between waste material technology and environmental impact mitigation strategies is a relevant and sustainable solution in answering environmental challenges due to increased waste generation. The use of waste as alternative raw materials, such as recycled plastic for paving blocks, fly ash for geopolymers, and organic waste for compost, is not only able to reduce the volume of waste but also produce products that have economic value and are environmentally friendly. The success of this approach is largely determined by the availability of technology that is in accordance with local conditions and community capabilities. Appropriate technology, which is simple, efficient, and cost-effective, is an important pillar in expanding the adoption of waste treatment at the grassroots level. On the other hand, adequate environmental mitigation policy support and strategies also play an important role in creating an ecosystem that supports integration between technological innovation and environmental protection. Incentive policies, public education, and the application of the principle of extended producer responsibility are clear examples of the contribution of mitigative strategies in strengthening system sustainability. In addition to the technical and policy aspects, multi-stakeholder collaboration is proving to be a key element of success. The simultaneous involvement of the community, academia, government, and the private sector creates synergies that allow the implementation of technology to run effectively, be socially accepted, and be long-term resilient. This transdisciplinary approach not only broadens the support base for innovation, but also raises collective awareness of the importance of responsible waste management. Overall, this integrative approach not only brings the two domains together—technology and the environment—but also fosters awareness of the importance of seeing waste as an opportunity, not just as a problem. Therefore, the integration of technology and mitigation strategies must continue to be developed as part of the sustainable development agenda that balances economic needs, social welfare, and environmental sustainability.

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