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EVALUATION OF THE PYROLYSIS PROGRAMME BY THE ENVIRONMENTAL AGENCY OF CENTRAL SULAWESI PROVINCE AS A SUSTAINABLE WASTE MANAGEMENT SOLUTION IN BESUSU BARAT VILLAGE, PALU CITY

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Abstract

Plastic waste management is an increasingly pressing environmental issue, particularly in urban areas, due to rising waste generation outpacing effective management systems. As an innovative effort, the Environment Agency of Central Sulawesi Province initiated a pyrolysis programme to process plastic waste into fuel oil, supporting sustainable waste management in Besusu Barat Village, Palu City. This study aims to evaluate the implementation of the pyrolysis programme as a sustainable waste management solution using the CIPP evaluation model (Context, Input, Process, Product). The research adopts a qualitative, case-study design. A total of six informants were selected through purposive sampling, comprising government officials, programme implementers, waste bank managers, and community members. Data were collected through observation, in-depth interviews, and documentation. Data analysis employed content analysis with source and method triangulation techniques to ensure data validity. The findings reveal that, in terms of context, the pyrolysis programme aligns with the need to reduce plastic waste and is consistent with government policies. Regarding input, the programme is supported by the availability of technology, regulations, and partnerships, although limitations in human resources and funding persist. In the process aspect, programme implementation follows the established mechanisms, yet community participation and operational consistency remain suboptimal. As for the product, the programme has succeeded in reducing the volume of plastic waste and producing alternative fuel oil, although its effectiveness still requires improvement. The study concludes that the pyrolysis programme by the Environment Agency of Central Sulawesi Province has the potential to serve as a sustainable waste management solution at the community level. However, it requires strengthening in terms of resources, community participation, and operational sustainability to ensure more effective and sustainable implementation.

Keywords: Program Evaluation, Pyrolysis, Waste Management, CIPP

Introduction

Waste management is an increasingly pressing global environmental issue due to population growth, urbanization, and unsustainable consumption patterns. The World Bank projects global waste production to increase from 2.01 billion tons in 2016 to 3.40 billion tons by 2050 without significant intervention (Oktavilia et al. 2024). Conventional waste management systems, such as landfills, contribute to environmental pollution and greenhouse gas emissions, prompting the development of alternative technologies such as pyrolysis as a more sustainable solution.

The issue of plastic waste is a major concern, as production has exceeded 430 million tons per year, with approximately 50% of it inadequately managed (UNEP 2023). More than 11 million tons of plastic are estimated to enter the oceans annually, and this figure has the potential to increase

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dramatically without systemic intervention (Jambeck et al. 2015). In addition to ecological impacts, microplastics also threaten human health because they can accumulate in vital organs and trigger inflammation and oxidative stress(O'Leary 2024).

In Indonesia, waste generation reaches 32.8 million tons per year, with approximately 39% not being properly managed (KLHK 2024). Low recycling rates, limited infrastructure, and minimal public participation are the main challenges to national waste management (Sumirat 2023). Community involvement is crucial because most waste originates from households, in line with the Theory of Planned Behavior, which emphasizes the role of attitudes and social norms in shaping environmentally friendly behavior (Ajzen 1991).

The Indonesian government is targeting a 30% waste reduction and 70% waste management by 2025 through Presidential Regulation No. 97 of 2017, while also supporting the achievement of SDGs Goals 11 and 12 (UNDP 2020). In this context, pyrolysis technology was introduced as an innovation in plastic waste processing capable of producing value-added products and supporting a circular economy (Adicita, Sari, and Suryawan 2023).

At the regional level, Central Sulawesi Province produces more than 212,000 tons of waste annually, with plastic accounting for 16–19% (KLHK 2023). The local government developed the Central Sulawesi Recycle Center (SRC) based on pyrolysis as part of the BERANI BERSIH program, which converts plastic waste into fuel and provides economic benefits to the community. The success of this technology is influenced by policy support, investment, and community participation (Dennison et al. 2025).

Based on this context, this study aims to evaluate the pyrolysis program implemented by the Central Sulawesi Provincial Environmental Service as a solution for sustainable waste management in Besusu Barat Village, Palu City.

Method

This research uses a qualitative approach aimed at deeply understanding social phenomena through the experiences, perceptions, behaviors, and dynamics of the actors involved, without relying on quantitative data. The qualitative approach emphasizes holistically exploring meaning through descriptive data analyzed inductively, so that conclusions are drawn from patterns emerging in the field data (Sinaga 2023).

According to John W. Creswell (2014), qualitative research is exploratory and focuses on understanding the meanings individuals or groups construct regarding a social problem. In line with this, this research was conducted through direct observation of relevant Regional Apparatus Organizations (OPDs), using a case study approach as a research strategy.

A case study is an approach used to examine a phenomenon in depth within a real-life context, especially when the boundaries between the phenomenon and its context are not clearly visible (Robert K. Yin, 2018). In this research, the case studied is the implementation of a pyrolysis technology program by the Central Sulawesi Provincial Environmental Agency for sustainable waste management. The case study approach allows researchers to comprehensively understand the program implementation process, the actors involved, and the dynamics that occur during implementation.

Results

This research was conducted at the Central Sulawesi Provincial Environmental Agency located in Palu City, as an agency with strategic authority in the formulation and implementation of environmental management policies at the provincial level. One of the programs developed is the Pyrolysis Utilization Program as an effort for sustainable waste management, which is implemented in the Besusu Barat Village. In this program, the Central Sulawesi Provincial Environmental Agency acts as the policy manager and technical supervisor, while the Besusu Barat Village serves as the implementation location representing the program's implementation at the community level. The linkage between provincial policy and implementation at the village level is the focus of the evaluation to assess the effectiveness of the pyrolysis program as a solution for sustainable waste management.

This research was conducted in the period from October 3, 2025 to February 6, 2026, covering the stages of preparation, data collection, data analysis, and preparation of recommendations for sustainable waste management strategies.

The informants in this study numbered six people, consisting of the Head of the Central Sulawesi Provincial Environmental Service, the Head of Besusu Barat Village, pyrolysis operators, representatives of the Besusu Barat community, and the waste bank.

This study aims to assess the effectiveness of the pyrolysis program by DLH Sulteng as a sustainable waste management solution in Besusu Barat Village, Palu City. The study was conducted using Stufflebeam (1971) CIPP (Context, Input, Process, Product) model.

Discussion Of Research Results

1. Context

In the CIPP evaluation model, the context component aims to assess the program's relevance to real needs, emerging issues, and strategic opportunities within the social, policy, and ecological contexts. This evaluation not only identifies problems but also assesses the program's appropriateness as a response to these conditions.

Interviews with the Central Sulawesi Provincial Environmental Agency, village governments, and waste bank managers indicate that the Pyrolysis Program was motivated by the increasing generation of difficult-to-decompose plastic waste that dominates the waste composition. This situation demonstrates clear problem recognition, namely the recognition of a pressing environmental issue that requires innovative solutions.

This finding aligns with a United Nations Environment Programme (UNEP, 2023) report stating that the plastic waste crisis has reached an alarming level and requires a systemic, technology-based approach and changes in community behavior. Lau et al. (2020) also assert that without innovative interventions, plastic leakage into the environment will continue to increase in the coming decades. Therefore, the pyrolysis program is considered ecologically relevant because it addresses the region's real needs.

From an Islamic perspective, QS. Ar-Rum verse 41 emphasizes that damage to land and sea is the result of human actions, therefore waste management efforts and environmentally friendly technological innovation are part of humanity's moral responsibility to remedy these impacts. This strengthens the program's ecological and normative relevance.

From a policy perspective, this program is supported by Law Number 18 of 2008 concerning Waste Management and Central Sulawesi Governor's Instruction Number 2 of 2025, thus enjoying strong structural legitimacy. Arisman and Fatimah (2023) emphasize that regulatory support is a key factor in the success of waste management innovations. Kirchherr et al. (2017) also state that the transition to a circular economy is greatly influenced by consistent public policies promoting the use

of waste as a resource. Therefore, this program aligns with national and global policy directions regarding waste reduction and resource efficiency.

However, challenges remain on the social dimension. Interviews indicate that public understanding of the mechanisms and benefits of pyrolysis technology is still limited. This indicates a gap between objective need and perceived need, where the program is structurally needed but has not yet been fully internalized as a shared need. These findings align with Listyarini and Warlina (2023), who stated that the success of environmental technology innovation is influenced by literacy levels and social acceptance, and Jung et al. (2024), who emphasized the importance of ongoing public education in waste-to-energy programs.

Surah Ar-Ra'd, verse 11, emphasizes that the change in the condition of a people depends on the change in themselves. This verse reinforces the importance of transforming collective consciousness and community participation as an integral part of evaluating the program's context.

From a strategic perspective, utilizing plastic waste as an alternative fuel is seen as an innovation that supports resource efficiency and alternative energy. This aligns with the International Energy Agency (IEA, 2023) report on energy diversification in sustainable transitions, as well as Geissdoerfer et al. (2017), who emphasize the importance of shifting from a linear system to a circular economy. Surah Al-Hashr, verse 18, also provides an ethical dimension regarding the importance of a long-term sustainability orientation.

Overall, the context evaluation indicates that the Pyrolysis Program has strong ecological, policy, and global strategic relevance. This program arose from a real need, is supported by adequate regulations, and aligns with circular economy trends and the energy transition. However, the social dimension particularly literacy and community participation still requires strengthening to optimally align objective needs with perceived needs.

Thus, from the CIPP perspective, the context variable of the Pyrolysis Program can be categorized as on-target, but requires strengthening in the internalization of social needs to ensure comprehensive ecological, policy, and moral-spiritual sustainability.

2. Input

Input aspects in the implementation of the pyrolysis program include policy, human resources, infrastructure, funding, institutional support, technology, and community readiness. Overall, the program has an adequate foundation, although limitations remain that impact optimal implementation.

Policy-wise, the program aligns with Central Sulawesi Governor's Instruction Number 2 of 2025 and Law Number 18 of 2008 concerning Waste Management, which encourages the use of environmentally friendly technologies. The selection of pyrolysis technology is considered appropriate because it can process plastic waste without open combustion and produce a valuable alternative fuel. This finding aligns with Rosyidatuzzahro & Anisykurlillah (2024), who emphasized the importance of policy readiness and institutional support for program success.

As a comparison, developments by the West Nusa Tenggara Regional Research and Innovation Agency (BRIDA) demonstrate the importance of integrated input planning within the master plan and the combination of technologies such as Refuse Derived Fuel (RDF). This confirms that program success is determined not only by regulations but also by capacity planning and system integration. Compared to West Nusa Tenggara (NTB), policy aspects in West Besusu are relatively well-established, but integrated planning and formal collaboration still need to be strengthened. This effort aligns with Surah Al-A'rāf, verse 56, concerning the prohibition of destroying the earth.

In terms of human resources, operators assigned by the Provincial Environmental Agency (DLH) have undergone technical training, thus developing basic operational competencies. Infrastructure such as personal protective equipment and security systems are also available, although

the operational location remains semi-open. This precautionary principle is relevant to Surah Al-Baqarah, verse 195.

Program funding is supported through partnerships and Corporate Social Responsibility (CSR) funds in addition to the regional budget (APBD). This pattern reflects the principle of cooperation in Surah Al-Māidah, verse 2, but does not guarantee long-term financing sustainability.

Institutionally, there are no written Standard Operating Procedures (SOPs), and cross-party collaboration remains informal. This situation has the potential to undermine program sustainability and emphasizes the importance of the principle of trustworthiness as stipulated in Surah Al-Baqarah. An-Nisa' verse 58.

Community readiness is also still limited due to a lack of outreach, resulting in suboptimal participation in raw material provision. This aligns with QS. Ar-Ra'd verse 11, which discusses the importance of changing collective consciousness. Furthermore, limited supporting technology, such as drying machines, impacts operational efficiency. This finding is consistent with those of Baihaqi and Hartati (2025), Sulkifli et al. (2024), Allysa and Wijayanti (2023), and Ridwan et al. (2022), who emphasized the importance of strengthening institutional and social aspects for the sustainability of environmental technology innovation.

Overall, the input variables of the pyrolysis program are adequate in terms of policy and core technology, but still require strengthening in terms of SOPs, formal institutions, funding stability, the completeness of supporting technology, and increasing community literacy and participation. This aligns with QS. Al-Hasyr verse 18, which discusses the importance of a long-term sustainability orientation.

Therefore, from the CIPP perspective, the input aspects can be categorized as quite ready, but require systemic strengthening for the program to run optimally and sustainably.

3. Process

Based on interviews, the process aspects of the pyrolysis program implementation in West Besusu Village indicate that the program is operationally running, but is still in the strengthening and consolidation stages. Internally, the process has been designed through an institutional structure that regulates the flow of plastic waste processing, from raw material receipt to fuel oil (BBM). Monitoring and evaluation are carried out by the Central Sulawesi Provincial Environmental Agency based on a Decree of the Head of the Agency, with a clear division of duties. This orderly and systematic work aligns with Surah Ash-Shaff, verse 4, which emphasizes the importance of orderly ranks in achieving common goals.

Technically, the processing at the SRC facility is equipped with an operational logbook that records the amount of incoming waste, the volume processed, and the frequency of machine operation. The pyrolysis machine is run twice a week through the stages of sorting, drying, heating, and regular maintenance. However, the frequency of operation is still limited, primarily due to the dependence on the availability of supporting materials such as gas, resulting in suboptimal production.

Institutionally, the implementation process is still dominated by internal coordination between the management. The roles of the village and the community have not been formally integrated, as there is no written agreement between the village and the Environmental Agency. Village involvement is still limited to meetings and initial outreach. This situation indicates a lack of clarity on responsibilities between actors, as emphasized in Surah An-Nisa', verse 58.

At the community level, involvement is still limited and not supported by ongoing outreach. Information regarding the mechanisms and types of plastic that can be processed is mostly obtained during the program's inauguration. This low level of participation is relevant to Surah Ar-Ra'd, verse 11, which emphasizes the importance of changing collective consciousness.

The plastic waste collection process still relies on waste banks as intermediaries. Economic factors influence community participation, as the selling price to collectors is often more competitive than program incentives. The role of waste banks as social connectors aligns with the principle of cooperation in Surah Al-Māidah, verse 2, although they face challenges such as limited capital and fluctuating market prices.

Technically, operators carry out the process according to the training they have received, including sorting according to machine specifications, managing moisture content, scheduling operations, and maintaining equipment. The machines are considered relatively safe, but limited supporting facilities, such as dryers, and limited operating schedules, impact efficiency.

Overall, the process aspect has been implemented at the technical and administrative levels, but has not been optimally integrated across actors. The process remains top-down, with limited community participation. The lack of ongoing socialization, the lack of competitive economic incentives, and the absence of formal coordination between institutions impact the program's effectiveness.

This finding aligns with those of Ernawati et al. (2023), who assert that the implementation of waste processing technology is not optimal without ongoing socialization; temTomimi (2024), who emphasizes the importance of formal institutional structures; Helpiastuti and Jahro (2019) regarding the strategic role of waste banks; Haniyah et al. (2023) regarding the importance of economic incentives; and Lu (2022), who indicates that limited supporting infrastructure impacts the optimization of pyrolysis technology.

Therefore, from the CIPP perspective, the process variable can be categorized as ongoing but not yet optimal, necessitating strengthened coordination across actors, ongoing socialization, structuring the incentive system, and improving infrastructure support to make the program more participatory and sustainable.

4. Output

The research results show that the pyrolysis program has produced both physical and non-physical outputs, but they are still limited and uneven. With a machine capacity of 20 kg per cycle, the impact on reducing plastic waste in Palu City has not been significant. Nevertheless, in nearly two months of operation, approximately 200 liters of fuel have been produced, which are used by fishermen and farmers. This gradual achievement aligns with the verses of QS. Al-Insyirah, verses 5–6, which emphasize that there is ease after hardship.

In terms of quality, the fuel produced by pyrolysis has met quality standards based on laboratory tests and has been empirically proven suitable for use by farmers, with good combustion properties and no damage to engines. This demonstrates that the program's outputs are functional and tangible, as emphasized in QS. Az-Zalzalah, verse 7, that every good deed, no matter how small, will yield results.

However, the perception of the West Besusu community is not entirely positive because the distribution of benefits is still limited and there are no clear economic incentives. Limited production capacity and the lack of an integrated compensation scheme mean that the outputs have not yet had a significant socio-economic impact. This situation is relevant to QS. Al-Baqarah verse 286 addresses the alignment of results with capacity.

In addition to material output, increasing public knowledge and awareness about the potential of plastic waste as fuel is an important achievement. This sustainability orientation aligns with Surah Al-A'raf verse 56 and Surah Al-Mujādilah verse 11 on environmental protection and the importance of knowledge.

Overall, program output has been achieved but is not yet optimal. Increased production capacity, expanded benefit distribution, and the integration of economic incentives are needed to

make the program more impactful and sustainable. This finding aligns with Allysa and Wijayanti (2023), Ridwan et al. (2022), Auliani et al. (2024), and Salsabila et al. (2023), who emphasized that in the initial stages, technology-based program output tends to be partial and requires capacity building and benefit distribution.

Conclusion

Based on the evaluation results using the CIPP model, it can be concluded that the Pyrolysis Program implemented by the Central Sulawesi Provincial Environmental Agency is contextually aligned with the needs of addressing the increasing generation of plastic waste. This program arose from a real environmental need, aligns with government policy, and supports the principles of sustainable waste management. The designation of West Besusu Village as a pilot location reflects the support and commitment of the local government to encourage technology-based waste management innovation at the local level.

In terms of input, the pyrolysis program is supported by the availability of technology, the local government policy framework, human resources, and the availability of raw materials in the form of plastic waste. However, input readiness is not yet fully optimal. Limited human resource capacity and capacity, limited operational funding, and low community involvement in the program planning stage are factors that impact the overall effectiveness of the program's implementation.

In terms of process, the pyrolysis program has essentially been implemented in accordance with its initial objective, namely processing plastic waste into alternative fuels. However, the implementation process has not been optimal. This is demonstrated by the inconsistent equipment operating schedule, limited community outreach activities, and passive community participation, which has not been actively integrated into program implementation.

Meanwhile, in terms of output, the pyrolysis program has produced initial positive impacts in the form of reduced plastic waste volume and the use of processed products as alternative fuels. However, these impacts have not been widely felt by the community and are not supported by a measurable results monitoring system. This situation means that the program's sustainability and development still require strengthening, both in terms of increasing production capacity, expanding benefit distribution, and integrating program outputs with community economic and environmental needs.

Overall, the evaluation results indicate that the Pyrolysis Program has significant potential as a technology-based plastic waste management solution at the regional level. However, for the program to operate sustainably and achieve broader impact, strengthening the input, process, and output aspects is necessary, particularly through increasing resource capacity, strengthening community participation, and developing a more structured program management and monitoring system.

The Central Sulawesi Provincial Environmental Agency and the Besusu Barat Village government are advised to strengthen the management of the pyrolysis program through a clear plastic waste collection and sorting system, improved cross-sector coordination, and ongoing formal collaboration. Placing collection points closer to communities should also be considered to increase program effectiveness and environmental benefits.

Communities in Besusu Barat Village are expected to increase their participation by sorting waste at source and actively participating in the pyrolysis program once the system and outreach are running optimally. Sustainable participation is expected to support plastic waste reduction, environmental cleanliness, and the utilization of waste as a valuable resource.

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