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Critical Success Factors for Waste Management Startup Development in Indonesia: A DEMATEL-Based ANP (DANP) Analysis

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Abstract: Indonesia faces growing waste management challenges, while existing management efforts remain insufficient to address increasing waste generation. In response, waste management startups have emerged as innovative solutions. Despite their potential, many struggle due to weak regulation, technological barriers, and low public awareness. This study identifies Critical Success Factors (CSFs) influencing their development using the DEMATEL-based ANP (DANP) method, which captures interrelationships among 37 validated CSFs through expert judgment and modeling. The results indicate that Learning and Growth is the most prominent dimension, while Government Support acts as the primary driving dimension. At the global level, 'Government Policies and Regulation' has the highest priority, highlighting the importance of a supportive regulatory environment for startup development. These findings provide practical guidance for policymakers, entrepreneurs, and other stakeholders to strengthen the waste management startup ecosystem and advance sustainable waste management in Indonesia.

Keywords: Critical Success Factors; DEMATEL-based ANP (DANP); Green Entrepreneurship; Waste Management Startups

1. Introduction

Waste management remains a significant global challenge, with projections indicating a dramatic increase in the volume of waste and its adverse impacts on the planet in the coming decades. Global waste generation currently reaches approximately 2.2 billion tons annually, with about 33% of this waste not managed in an environmentally safe manner[1)]. A large proportion of waste is either incinerated or dumped in landfills, rivers, or oceans—contributing to severe environmental degradation[2-4)]. If left unaddressed, global waste is expected to increase by 70% by 2050[1,5)].

Indonesia is also experiencing a continual rise in waste generation each year, with no clear solution in sight. According to the Ministry of Environment and Forestry[6)], the volume of waste—particularly plastic waste—has consistently increased from 2013 to 2019. Several factors contribute to waste generation, including population size and growth rate, standard of living, lifestyle, population mobility, seasonal variation, and food consumption patterns. Urbanization also plays a role; for instance, per capita waste generation in urban areas (0.6 kg/person/day) is typically higher than in rural areas (0.3 kg/person/day)[6,7)]. Waste collection is a critical component of waste management, yet the quality and extent of collection services vary widely by income level. High- and upper-middle-income countries tend to provide near-universal waste collection. In contrast, low-income countries collect only about 48% of waste in urban areas, and this Figure drops sharply to 26% in rural regions[8)].

The growing waste problem has driven the emergence of innovators and entrepreneurs developing green startups. A green startup is defined as a platform that creates and implements products or services contributing to green economic goals, such as reducing greenhouse gas emissions, increasing energy efficiency, and adopting circular economy principles[9)]. Green startups differ from conventional startups primarily in their characteristics related to products, entrepreneurship, and strategic orientation[9,10)]. Among the various domains within green entrepreneurship, several studies show that waste management startups represent a key focus area[11–13)]. These startups typically aim to connect communities to nearby waste disposal or recycling facilities to ensure more appropriate and sustainable waste handling[10)]. Their

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offerings may include waste collection services, sorting, processing, education, consulting, and recycling activities[14].

Despite the growing number of waste management startups, most are still concentrated in major cities and have yet to expand into suburban and remote areas—regions that also face waste-related issues, often compounded by a lack of education and awareness on proper waste disposal[15,16]. Given that waste is an inevitable by-product of human activity, the demand for effective waste solutions will persist indefinitely. However, the development of waste management startups is not without its challenges. Waste management startups represent a form of green entrepreneurship that seeks to address environmental challenges while creating economic and social value through sustainable business models[9]. Unlike conventional startups, these ventures operate within complex institutional and regulatory environments and must balance commercial viability with environmental and social objectives, making business development particularly challenging[9].

Consequently, startup failure rates remain high globally, with estimates ranging from 50% to 90%[17–19]. Previous studies suggest that predicting startup success remains difficult because it depends on the complex interaction of managerial, organizational, market, and external environmental factors[20–22]. This suggests that certain factors strongly influence the success or failure of such ventures[23,24]. Without careful attention to these factors, it will be difficult for these startups to grow and scale.

Hence, it is essential to identify and analyze the most influential factors that contribute to the successful development of waste management startups. This research is motivated by the worsening waste problem in Indonesia and the limited capacity of landfills as a long-term solution. Waste management startups represent a promising alternative, but they must be strategically developed based on a clear understanding of the key factors that drive their success. This study therefore seeks to answer the research question: "What are the factors that influence the success of waste management startups, and how do these factors interrelate to help prioritize decisions for policy and business development?". The objective of this study is to analyze the Critical Success Factors (CSFs) that affect the growth and performance of waste management startups. The findings are expected to serve as a practical reference for startup founders and stakeholders, helping them identify priority areas in decision-making to enhance the development and sustainability of their ventures.

2. Literature Review

2.1. Waste Management Startup

Indonesia faces significant challenges in waste management due to its large population, archipelagic geography, and rapidly increasing waste generation. In 2024, national waste generation reached approximately 25.66 million tonnes, with organic waste (50%) and plastic waste (19%) constituting the largest proportions[25]. Although various waste treatment methods, such as recycling, composting, landfilling, and waste-to-energy technologies, have been implemented, previous studies have discovered that their effectiveness remains constrained by limited infrastructure, inconsistent policy implementation, and insufficient technological development[26–30]. These challenges create a complex operating environment while also presenting opportunities for waste management startups to introduce innovative and sustainable solutions. Consequently, Indonesia provides an important empirical context for investigating the critical success factors that influence the development of waste management startups, as the country's regulatory environment, infrastructure conditions, and evolving waste management startup ecosystem may shape both the importance and the interrelationships of these factors.

A startup is generally defined as an early-stage organization established to develop innovative products or services under conditions of high uncertainty[31]. Blank further describes startups as organizations searching for a repeatable and scalable business model[32]. Startup companies are commonly associated with technology-driven innovation and rapid growth. In this study, waste management startups refer to technology-based early-stage companies that play a role in managing waste through various products and services. Waste management is commonly classified based on the supply chain process. There are several stages: waste prevention, waste collection, waste sorting, waste processing, and product generation from waste management. To address waste-related challenges, startups have emerged in various countries to provide solutions and make waste management more accessible.

In Indonesia, which ranks fifth globally and second in Asia in terms of startup growth (startupranking.com), waste management startups have continued to increase. Between 2014 and 2016, nine startups were established, including Waste4Change, Gringgo, MallSampah, Cleanup, BebasSampah.id, EwasteRJ, Smash, Evo & Co, and Angkuts. From 2017 to 2019, another twelve startups were founded, such as Mulung.co, Magalava, Panongpong, Jangjo, Rekosistem, Sampah Muda, Mountrash, Oktopus, Pemolid, Reciki, Duitin, Nyampah Corp, and Goni-Goni, and it is still growing until now.

Despite this growing ecosystem, many waste management startups remain in the early stages of development and operate within Indonesia's complex waste management system. Therefore, identifying and understanding the critical success factors that influence the development of waste management startups is essential for supporting their long-term sustainability and enabling them to contribute

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more effectively to Indonesia's national waste management agenda.

2.2. Critical Success Factors (CSF)

The concept of success factors was first developed by D. Ronald Daniel and later refined by John F. Rockart[33], and it can be applied across various disciplines. According to Rockart, Critical Success Factors (CSFs) are "a few key areas" which, if results are satisfactory, will ensure competitive performance for an organization. Therefore, Rockart emphasized that these factors must receive careful and continuous attention from management[33].

CSFs are derived from an organization's mission and objectives. Management must determine what needs to be accomplished to achieve success, and these factors tend to be universal across organizations. Examples include increasing profits, enhancing employee engagement, improving talent acquisition and retention, and becoming more environmentally sustainable.

Previous studies on startups in Indonesia have identified a range of CSFs influencing startup development. These include government support, managerial experience, funding accessibility, organizational size, and innovative products or services[34], as well as synergy, product development, innovation management, information technology, communication, organizational culture, experience, and implementation skills[33]. Other studies have further highlighted that the regulatory environment and market competition also play important supporting roles[34]. Although these studies provide valuable insights into startup success in Indonesia, they primarily focus on startups in general rather than waste management startups. Consequently, limited attention has been given to how the unique characteristics of Indonesia's waste management ecosystem may influence the critical success factors of waste management startups.

In this study, both internal and external industry CSFs are considered, given the similarities across business sectors. Industry CSFs can be translated into competitive advantage activities that align with business strategic objectives, thereby creating greater opportunities to increase market share in fragmented industrie[34]. Although originally applied in project management studies, CSFs are now used across a wide range of disciplines.

2.3. DEMATEL-based ANP (DANP)

The DEMATEL method was introduced by the Battelle Memorial Institute through the Geneva Research Centre and developed to address complex problem[35]. DEMATEL is a comprehensive approach designed to model and analyze the causal relationships among multiple factors[36]. The results of the DEMATEL method reveal reciprocal relationships among components and can be used to identify which factors influence one another or themselves. However, the Analytical Network Process (ANP) is a mathematical theory that enables decision-makers to systematically address interrelated factors and feedback relationships. ANP is one of the multi-criteria decision-making methods developed by Thomas L. Saaty[37].

DEMATEL could complement the ANP method, as it allows the determination of interdependencies among factors across different dimensions to be more objective. Thus, combining the two methods (ANP and DEMATEL) provides a more accurate solution for addressing dependence and feedback, as well as better reflecting real-world situations[38].

Critical Success Factors (CSFs) may influence one another, and these interrelationships serve as inputs for the subsequent processing stage using the ANP method. Since constructing an ANP network structure requires a solid foundation regarding the interrelationships among CSFs, DEMATEL provides valuable information about their causal links[38]. A causal relationship indicates that one CSF exerts influence on another, whereas an effect relationship occurs when a CSF is influenced by others. Such cause-effect information is highly useful in forming the network structure and in conducting ANP pairwise comparisons, considering the potential for dependence and feedback (i.e., mutual influence among CSFs and self-influence). Therefore, integrating the two methods helps to resolve issues of dependence and feedback[38], while also producing more accurate priority weights.

Since the CSFs influencing waste management startups are interrelated rather than independent, an analytical method capable of capturing both causal relationships and relative priorities is required. The integrated DANP approach enables the identification of these interdependencies while simultaneously determining the importance of each factor. Therefore, DANP provides a more comprehensive representation of the complex interactions among the critical success factors than methods that assume independent evaluation criteria.

3. Materials and Methods

This study aims to identify and analyze the Critical Success Factors (CSFs) that influence the success of waste management startups in Indonesia. CSFs refer to key elements or activities that significantly affect an organization's success in achieving its goals. According to Rockart[31], CSFs are 'a few key areas' where favorable outcomes are essential for ensuring competitive performance. Therefore, these factors must receive consistent and careful attention from management.

An initial list of 43 CSFs across 8 dimensions—Learning and Growth, Organization, Environment, Technology, Financial, Government Support, Strategy, and Innovation—was developed through a literature review and expert interviews. These factors were then presented in Table 1 and served as the foundation for the

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questionnaire design.

3.1. Exploration and Initial Identification of Critical Success Factors (CSFs)

The first stage of data collection involved CSF validation through expert assessment. Experts invited for validation were selected with criteria including senior managerial or founder roles in waste management startups, active involvement in decision-making processes, and a minimum of 3 years of experience in the waste management startup sector. A total of four experts from different institutions participated in this stage, each having between 5–10 years of relevant experience. The validation was conducted through interviews and online questionnaire completion via Zoom or offline.

During this validation process, each expert rated the 43 factors using a 4-point relevance scale: 1 (Not Relevant), 2 (Slightly Relevant), 3 (Moderately Relevant), and 4 (Highly Relevant). Based on the I-CVI (Item-level Content Validity Index) analysis, six CSFs were eliminated due to low relevance scores: Integrated Management Information (OR5), Competitive Pressure (EN2), Workplace Management (EN7), Technological Surveillance (TE4), Government Financial Support (GS3), and End-User Participation (ST6).

Table 1: CSF of Waste Management Startup

Dimension	Code	Critical Success Factor	I-CVI	Inter-pretation
Learning and Growth	LG1	Awareness, training and education[39]	1	Valid
	LG2	Business performance review[40]	1	Valid
	LG3	Professional knowledge[40]	1	Valid
Organization	OR1	Top management support[41]	1	Valid
	OR2	Clear vision[41]	1	Valid
	OR3	Adequate human resources[41]	1	Valid
	OR4	Organizational Culture[41]	1	Valid
	OR5	Integrated management information[42]	0.75	Not Valid
	OR6	Strong management and leadership[43]	1	Valid
	OR7	Owner's/ stakeholder active participation and commitment[44]	1	Valid
	OR8	Team motivation[44]	1	Valid
Environment	EN1	Selection of vendors[41]	1	Valid
	EN2	Competitive pressure[41]	0.75	Not Valid
	EN3	Thinking development[43]	1	Valid
	EN4	Continuous improvement[45]	1	Valid
	EN5	Efficiency[43]	1	Valid
	EN6	Societal issues[46]	1	Valid
	EN7	Workplace management[46]	0.5	Not Valid
	EN8	Brand image and market share[47]	1	Valid
Technology	TE1	Compatibility of technology[41]	1	Valid
	TE2	Data quality[41]	1	Valid
	TE3	Traceability systems[42]	1	Valid
	TE4	Technological surveillance[48]	0.5	Not Valid
Financial	FI1	Adequate financial resources[49]	1	Valid
	FI2	Investment recovery[42]	1	Valid
	FI3	Stage financing[48]	1	Valid
	FI4	Effective cost management[44]	1	Valid
	FI5	Funding support for R&D[50]	1	Valid
	FI6	Investment rate[51]	1	Valid
Government support	GS1	Government policies and regulation[52]	1	Valid
	GS2	Strong legislation[50]	1	Valid
	GS3	Financial support from government[51]	0.75	Not Valid
Strategy	ST1	Customer focus[43]	1	Valid
	ST2	Communication[39] strategy	1	Valid
	ST3	Policy oriented[47]	1	Valid
	ST4	Market Orientation[47]	1	Valid
	ST5	Business model[53]	1	Valid
	ST6	End user's participation[44]	0.75	Not Valid
	ST7	Project risk management[44]	1	Valid
	ST8	Effective project planning and control[44]	1	Valid
Innovation	IN1	Innovative management approaches[49]	1	Valid
	IN2	Reverse logistic practice[50]	1	Valid
	IN3	Progressive thinking[54]	1	Valid

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3.2. Expert Assessment of CSFs

The second stage involved distributing a more detailed questionnaire based on the validated list of 37 CSFs. In this stage, experts were asked to assess the mutual influence between each pair of CSFs, resulting in 1,332 pairwise comparisons. The assessments were recorded using a Likert scale ranging from 0 (no influence) to 4 (very strong influence).

Five domain experts from the Indonesian waste management startup ecosystem participated in this study. The experts were purposively selected based on their professional experience and active involvement in waste management startup development. They represent diverse organizations and functional roles, including founders, chief operating officers (COOs), a head of communication and engagement, and a researcher specializing in waste management. All experts had more than three years of experience in the sector, with one expert having 10–15 years of experience, two experts having 5–10 years, and two experts having 3–5 years.

Considering that the waste management startup ecosystem in Indonesia is still relatively young, individuals with more than three years of continuous experience were considered to possess sufficient domain expertise to provide reliable assessments for the DANP analysis. The questionnaires were distributed online via Google Forms to allow flexibility in completion. Each expert completed the questionnaire independently based on their professional knowledge and experience in the waste management startup sector. When clarification regarding the meaning of a factor or the assessment procedure was required, the researchers provided explanations to ensure a consistent understanding of the questionnaire without influencing the experts' judgments.

The data gathered from this stage formed the input for the next phase of analysis using the DANP method, which integrates expert judgments into a quantitative model to determine the relative importance and influence of each CSF in the network.

3.3. Methods

The data collected in this study were analyzed using the DEMATEL-based ANP (DANP) method, a hybrid Multi-Criteria Decision-Making (MCDM) approach that combines the strengths of DEMATEL (Decision Making Trial and Evaluation Laboratory) and ANP (Analytic Network Process). This method can provide complete decision-making and is designed to solve performance evaluations[38]. DEMATEL-based ANP (DANP) is one of the most suitable methods for capturing the interactions and interdependencies among dimensions and criteria that occur in real-world situations, making it well suited for analyzing complex systems such as startup ecosystems[55].

Unlike the traditional ANP method proposed by Saaty, which relies on subjective pairwise comparisons and requires a Consistency Ratio (CR) check, this study adopts the novel DANP approach developed by Yang and Tzeng (2008). In this approach, the unweighted supermatrix is derived directly through the transposition and row-normalization of the DEMATEL total-relation matrix (T). Because the dependencies and feedback relationships are determined entirely by the mathematical properties of the total-relation matrix rather than separate pairwise matrices, traditional consistency index (CI) and consistency ratio (CR) thresholds are inherently bypassed[56].

Previous studies have successfully applied DANP in areas such as marketing strategy, vendor selection, and information security risk control[57,58]. In the DANP approach, the DEMATEL method is used to construct the Influential Network Relation Map (INRM), which illustrates causal relationships among criteria. The output of DEMATEL is then used as input in the ANP method, which assigns weights to the elements and dimensions. Through this process, the method not only assesses dependencies and interactions but also produces a weighted supermatrix used for prioritization.

According to Ramkumar & Jenaman[59], the DEMATEL-based ANP method is carried out with the following steps:

a) Step 1: Constructing the Initial Average Matrix (A)

Create an initial average matrix (A) = [A_ij]_(n × n). Expert respondents were asked to give a weighted value of the influence of one factor on other factors using a scale ranging from 0 (no influence) to 4 (very strong influence). Get the average matrix A by averaging the influence weight values between factors from five experts and form a pair comparison matrix.

b) Step 2: Calculating the Direct Influence Matrix (X)

Matrix A is then normalized to produce the direct influence matrix X, in which all diagonal values are set to zero. This normalization ensures comparability across factors and is conducted using the maximum row or column sum of matrix A.

c) Step 3: Calculating the Total Influence Matrix (Tc)

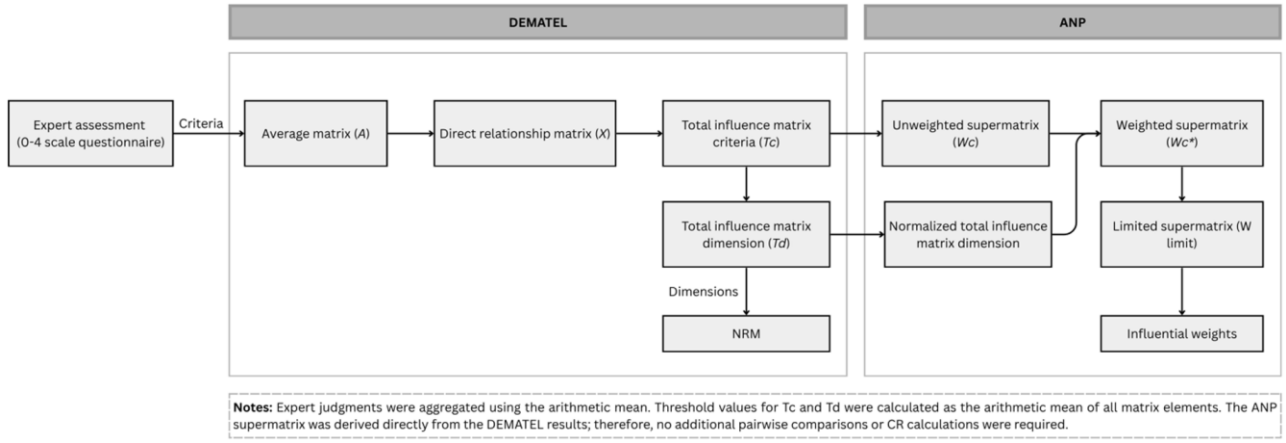
The total influence matrix Tc is calculated to capture both direct and indirect relationships among the factors. From the matrix that has been formed, the identity matrix is subtracted from X, the inverse of the resulting matrix is then obtained, and the result is multiplied by the X matrix to form the total CSF influence matrix (Tc). $Tc = X\,(I - X)^{-1}$, where I is the identity matrix, and represents the cumulative effects of indirect relationships among the factors.

d) Step 4: Calculating the Total Influence Among Dimensions (Td)

The Td matrix is then formed by averaging the values of each element on the same dimensions of the Tc Matrix.

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Fig. 1: DANP procedure (adapted from Chen and Lin (2018)[60])



e) Step 5: Analyzing the Results of the Total Influence Matrix (Tc)

Start by calculating the values of r (sum of rows) and s (sum of columns), then perform calculations of (rs) and (rs). The sum of the row elements with the column (ri + si) as the horizontal axis, the summation is calculated to show the level of importance of each CSF. Then the row element subtraction operation is carried out with the column (ri – si) as the vertical axis, which shows the level of influence. If the result is positive, then the factor tends to affect other factors; otherwise, if the result is negative, it means that the factor tends to be influenced by other factors. This analysis results in the Network Relations Map (NRM), which visualizes the causal structure.

f) Step 6: Normalizing the Total Influence Matrices (Td and Tc)

The total dimension influence matrix (Td) corresponds to the m dimensions/clusters derived from the total influence matrix (Tc). The Td Matrix is normalized by dividing each element by the number of each row in that element. Likewise, the Tc Matrix is normalized by dividing the elements in the Tc matrix by the number of elements of the same dimension in the row to produce a Tcnor matrix.

g) Step 7: Constructing the Unweighted Supermatrix (Wc)

Transposing the Tcnor matrix will produce a Wc matrix. If some matrix blocks are zero, it indicates independence between those clusters.

h) Step 8: Constructing the Weighted Supermatrix (Wc*)

Create a weighted supermatrix (Wc*) to get the weighted effect of DEMATEL-based ANP. The unweighted supermatrix (Wc) is grouped according to its dimensions and multiplied by the normalized Td Matrix (Tdnor) and the resulting weighted supermatrix (Wc*).

i) Step 9: Forming the Limit Supermatrix

The weighted supermatrix (Wc*) is increased until the value in a dimension is more uniform and tends to be stable.

The overall research procedure is illustrated in Figure 1. First, the critical success factors (CSFs) for waste management startup development were identified through a comprehensive literature review and categorized into eight dimensions. Five domain experts with experience in the Indonesian waste management startup sector were then invited to evaluate the direct influence among the identified factors using a five-point scale ranging from 0 (no influence) to 4 (very high influence). The individual assessment matrices were aggregated using the arithmetic mean to construct the initial average direct-relation matrix, which served as the input for the DEMATEL analysis. The DEMATEL procedure was subsequently used to generate the total relation matrices and identify the causal relationships among the dimensions and indicators. Finally, the normalized total relation matrix was transformed into the ANP supermatrices to obtain the limit supermatrix, from which the global weights and priority rankings of the critical success factors were derived.

4. Results

The summation and subtraction operations of the vectors r and s were used to construct the Network Relations Map (NRM), which is useful for understanding both the magnitude and direction of influence among Critical Success Factors (CSFs) as well as across dimensions. The NRM is presented as a directed graph that visually connects CSF elements based on their relationships.

In the NRM, the X-axis represents the value of (ri + si), indicating the overall importance of each factor, while the Y-axis represents (ri − si), showing whether a factor is primarily an influencer (positive value) or is influenced by others (negative value). To determine which relationships should be depicted in the graph, a threshold value was used. Only relationships with values above the average in the total influence matrix (Tc) and total dimension matrix (Td) were included.

Following the standard DEMATEL approach, the threshold value is obtained by calculating the average influence value on the Tc and Td matrices[61–64].

Table 2: Summary of Importance and Influence of Td (Across Dimensions)

Dimension	Code	r	s	r + s	r – s	Group
Learning and Growth	LG	1.120	1.083	2.203	0.037	Influencing
Organization	OR	1.013	1.091	2.104	-0.077	Being influenced
Environment	EN	1.015	1.066	2.081	-0.051	Being influenced
Technology	TE	1.027	0.953	1.980	0.074	Influencing
Financial	FI	1.006	0.990	1.996	0.015	Influencing
Government Support	GS	0.909	0.790	1.698	0.119	Influencing
Strategy	ST	0.962	1.047	2.009	-0.086	Being influenced
Innovation	IN	1.003	1.035	2.038	-0.032	Being influenced

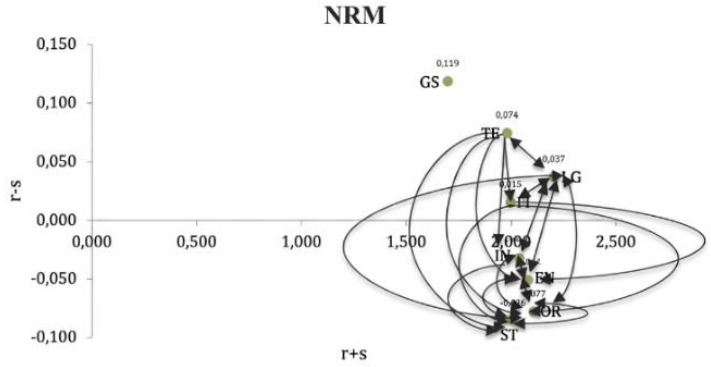


Fig. 2: Network Relation Map of CSF dimensions

Accordingly, the threshold for the total influence matrix (Tc) was obtained by averaging all elements of the Tc matrix, resulting in a value of 0.1285, while the threshold for the total dimension matrix (Td) was obtained by averaging all elements of the Td matrix, resulting in a value of 0.1258.

A higher value of $(r_i - s_i)$ indicates a stronger level of influence, whereas a lower or even negative value suggests that the factor is more likely to be influenced by others. As shown in Table 2, the Learning and Growth (LG) dimension has the highest level of importance, while the Government Support (GS) dimension is identified as the most influential factor.

Based on the data processing results, Figure 2 illustrates the relationships among the dimensions. The higher the position of a dimension on the vertical axis, the greater its influence on other dimensions; conversely, a lower position indicates that the dimension is more likely to be influenced by others.

As shown in Figure 2, the Government Support (GS) dimension exerts the strongest influence on the other dimensions, while the Strategy (ST) dimension tends to be more influenced by the others. These findings provide useful insights for stakeholders in waste management startups, particularly regarding the critical role of government support in their business operations. However, the Learning and Growth (LG) dimension has the highest (r+s) value, indicating the greatest level of prominence and positioning it farthest along the x-axis.

Figure 3 illustrates the relationships among Critical Success Factors (CSFs) within each dimension. In the Learning and Growth (LG) dimension, LG3 (Professional Knowledge) is positioned at the top right of the graph, indicating it has the highest values for both (r − s) and (r + s). This suggests that LG3 exerts a strong influence on other factors within the same dimension. Professional Knowledge refers to the set of theories and practices relevant to a specific field of work, typically acquired through formal education or training. It includes understanding theories, techniques, and principles that directly support performance in a professional role.

The Figure also highlights OR1 (Top Management Support) from the Organization (OR) dimension, which appears at the highest point on the y-axis and farthest to the right on the x-axis. This indicates that OR1 has the highest influence score and overall importance, reinforcing its role as a dominant factor in the organizational cluster.

Additionally, EN3 (Thinking Development) in the Environment (EN) dimension is located above the horizontal axis (y > 0), placing it within the group of influential factors. In the Technology (TE) dimension, TE2 (Data Quality) stands out as the most prominent factor, occupying the top-right position with the highest (r + s), while TE3 (Traceability Systems) has the highest positive (r – s) value, indicating that it is the most influential factor within the dimension. These results suggest that Data Quality plays a central role in the technology dimension due to its strong interactions with other technological factors, whereas Traceability Systems acts as the primary driver influencing the development of other technology-related factors.

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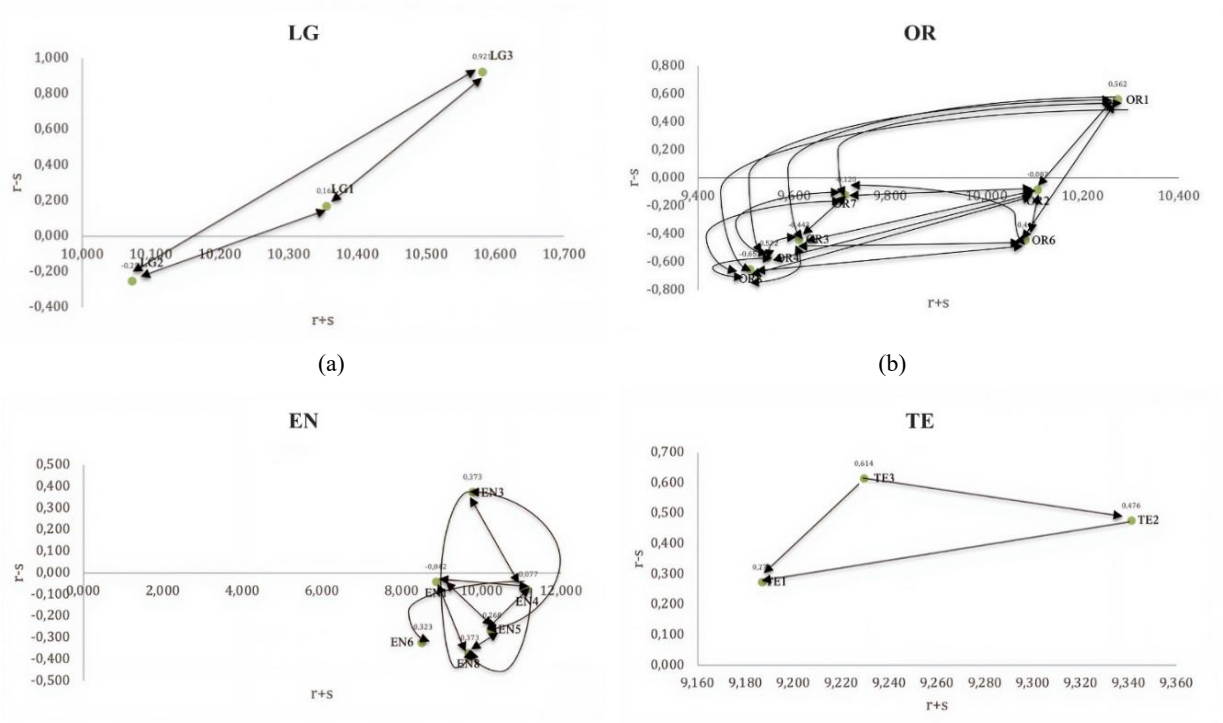


Fig. 3: Network Relation Map in Dimension (a) Learning & Growth, (b) Organization, (c) Environment, and (d) Technology dimensions

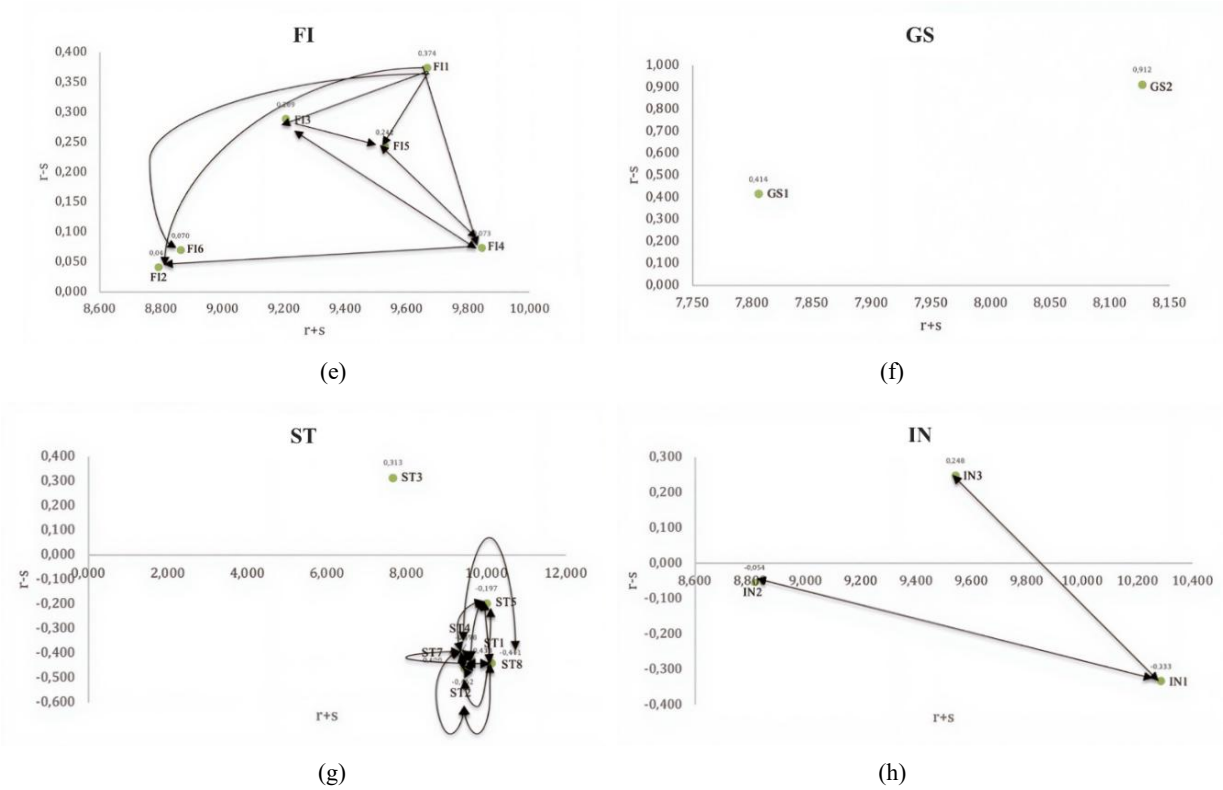


Fig. 4: Network Relation Map in Dimension (e) Financial, (f) Government Support, (g) Strategy, and (h) Innovation dimensions

As shown in Figure 4, in the graph of the CSF relationship on the Financial (FI) dimension, there is no negative (r – s) value. FI1 (Adequate financial resources) is included in the influencing group with the highest position, so it tends to give influence to other factors. The relationship between CSFs on the Government Support (GS) dimension shows that there is no relationship between the two different factors above the 0 line from the y-axis. This happens because both are external factors that are difficult for startups to control but can be followed up by continuing to

implement every policy that supports waste management. CSF on the dimension Strategy (ST) can be seen as follows: the Policy Oriented (ST3) is the only factor located above the horizontal axis ($r - s > 0$), indicating that it acts as the primary driving factor within the Strategy dimension. Progressive thinking factor (IN3), which has a positive value ($r - s$) and affects IN1. Reverse logistics practice (IN2), with the second highest position, shows the influence on the Innovative management approaches (IN1) factor. From Figure 4, it can be seen that if ($r - s$) is positive, then the factors included in the group affect other factors. However, if ($r - s$) is negative, then the factors included in the group tend to be influenced by other factors.

In comparison with global weighting matrices based on the level of influence, which cannot be done in the analysis using DEMATEL, the relationship of influence only applies to factors in the same dimension, but at the priority level, globally both between factors and between dimensions can be analyzed using ANP[65] with the output giving a ranking order of priority weights as shown in Table 3. This provides an opportunity that the factor with the highest priority level is not necessarily the factor with the highest level of influence. This classification is carried out to provide data-based analysis to obtain a conceptual model, while the decision to choose priorities can take different considerations.

5. Discussion

Based on the data processing results, the Government Support (GS) dimension emerged as the highest-priority dimension based on global weights, with GS1 (Government Policies and Regulations) and GS2 (Strong Legislation) ranked first and second, respectively. This was followed closely by IN1 (Innovative Management Approaches), as shown in Table 4.

The finding that Government Policies and Regulation (GS1) and Strong Legislation (GS2) emerged as the two highest-priority factors suggests that government intervention remains a key driver of waste management startup development in Indonesia. This result is consistent with previous studies, which identify government support as one of the most influential factors for startup success, particularly in developing economies where regulatory frameworks, infrastructure, and institutional support strongly affect entrepreneurial growth[32,66]. A well-designed regulatory environment not only reduces uncertainty but also encourages innovation, investment, and collaboration among ecosystem actors[67–69]

Indonesia has introduced several regulations to improve waste management, demonstrating the government's commitment to environmental protection. As noted by Nishimoto, the government plays a central role in setting these policies[70], as reflected in Government Regulation No. 81 of 2012 on Household Waste Management and Presidential Regulation No. 27 of 2020 on Specific Waste Management. These are derived from Law No. 18 of 2008, which redefines waste as an economic resource, thereby promoting entrepreneurial activity in the sector.

Table 3: The highest level of CSF in every dimension

DIMENSION	HIGHEST LEVEL OF IMPORTANCE	HIGHEST LEVEL OF INFLUENCE
Learning and Growth (LG)	Professional Knowledge (LG3)	Professional Knowledge (LG3)
Organization (OR)	Top Management Support (OR1)	Top Management Support (OR1)
Environment (EN)	Efficiency (EN5)	Thinking development (EN3)
Technology (TE)	Data quality (TE2)	Traceability Systems (TE3)
Financial (FI)	Effective cost management (FI4)	Adequate financial resources (FI1)
Government Support (GS)	Strong legislation (GS2)	Strong legislation (GS2)
Strategy (ST)	Effective project planning and control (ST8)	Policy oriented (ST3)
Innovation (IN)	Innovative management approaches (IN1)	Progressive thinking (IN3)

Table 4: Top 10 Priority CSF

CODE	CSF	GLOBAL WEIGHT	RANK
GS1	Government policies and regulation	0.0595	1
GS2	Strong legislation	0.0594	2
IN1	Innovative management approaches	0.0593	3
LG2	Business performance review	0.0582	4
LG1	Awareness, training and education	0.0569	5
LG3	Professional knowledge	0.0544	6
IN3	Progressive thinking	0.0517	7
IN2	Reverse logistic practice	0.0500	8
TE2	Data quality	0.0491	9
TE1	Compatibility of technology	0.0490	10

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Nevertheless, the regulatory framework could further support waste management startups by providing clearer recognition of their role within the waste value chain and ensuring more consistent implementation of existing regulations.

Previous studies have also pointed out that Indonesia's waste management sector continues to face regulatory fragmentation and governance challenges, including overlapping institutional responsibilities and limited coordination among stakeholder[71]. These conditions may explain why Strong Legislation (GS2) was ranked immediately after Government Policies and Regulation (GS1) in this study. Beyond establishing regulations, effective implementation, institutional coordination, and clear governance mechanisms are equally important for enabling waste management startups to scale and contribute to the circular economy.

Another finding is the high ranking of Innovative Management Approaches (IN1), which indicates that successful waste management startups require more than technological innovation alone. Since these startups operate within a complex ecosystem involving government agencies, waste collectors, recycling industries, investors, and local communities, effective managerial innovation is essential for coordinating stakeholders, adapting business models, and responding to evolving regulatory requirements. This interpretation is in line with previous studies that identify innovation management as a key success factor for Indonesian startups[33] and emphasize the importance of fostering innovation-oriented organizational cultures and management strategies within sustainability-oriented enterprises[72]. Rahman (2025) similarly argues that innovative business models in the waste management sector can only flourish within an enabling ecosystem supported by adequate infrastructure, funding mechanisms, and coherent policy instruments[71].

In response, startups should prioritize value creation that aligns with government policies, while also focusing on critical success factors within the Innovation (IN) and Learning and Growth (LG) dimensions, both of which significantly influence business performance. Meanwhile, competition among local waste management startups increasingly emphasizes creativity and continuous innovation[73]. These findings have practical implications for startup managers to prioritize organizational innovation alongside technological capability to enhance long-term competitiveness. Waste management startups have demonstrated the potential to revitalize economically marginalized areas through innovative practices, value chain optimization, and efficient resource utilization, ultimately contributing to waste reduction and improved environmental outcomes. Therefore, long-term success in this sector depends on effective innovation management, including strong leadership, structured innovation processes, collaboration capabilities, and strategic planning.

Although Data Quality (TE2) and Compatibility of Technology (TE1) were ranked ninth and tenth, the Technology (TE) dimension was identified as one of the dimensions that highly influences the other six dimensions in the NRM analysis. The difference between the DEMATEL and DANP results indicates that influence does not necessarily correspond to priority. Although the Technology dimension strongly influences other dimensions within the NRM, the global weights demonstrate that technology alone is insufficient to ensure startup success. This finding suggests that technological capabilities generate greater value when supported by enabling regulations, organizational capabilities, and innovation management, rather than being considered independently. Consequently, investments in technology should be accompanied by improvements in governance and managerial capacity to maximize their impact on startup development[74].

This also highlights that while technology strongly influences the system, its relative priority is lower when integrated with other dimensions. Therefore, developing a technology strategy should not only emphasize influence but also consider its position in overall priority. For instance, ensuring reliable data quality and seamless compatibility of technology remains essential to support innovative management approaches, strengthen performance review mechanisms, and facilitate the broader adoption of sustainable waste management practices throughout the value chain.

6. Conclusion

This study identified 37 validated Critical Success Factors (CSFs) that influence the development of waste management startups in Indonesia. These factors were categorized into eight dimensions: Learning and Growth (LG), Organization (OR), Environment (EN), Technology (TE), Financial (FI), Government Support (GS), Strategy (ST), and Innovation (IN). Among these dimensions, Learning and Growth has the highest level of prominence value (r + s), indicating that knowledge development, capability building, and continuous learning are fundamental in supporting the long-term success of waste management startups.

The analysis also reveals that Government Support is the main driving dimension, having the highest positive (r – s) value. This indicates that improvements in government support can influence many other aspects of startup development. In contrast, Organization, Environment, Strategy, and Innovation dimensions are primarily influenced by other dimensions, highlighting the need for coordinated efforts rather than isolated interventions. This suggests that strengthening upstream drivers, particularly

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government support, is likely to create broader improvements across the startup ecosystem rather than addressing individual factors independently.

Based on the ANP global weights, Government Support emerged as the highest-priority dimension, with Government Policies and Regulation (GS1) and Strong Legislation (GS2) ranked first and second among the individual CSFs, with global weights of 0.0595 and 0.0594, respectively. These results emphasize the important role of a supportive regulatory environment in fostering the growth of waste management startups. Clear and consistent government policies, effective legislation, and institutional support can encourage investment, promote innovation, strengthen stakeholder collaboration, and facilitate the adoption of sustainable waste management practices. Therefore, policymakers should prioritize the development of an enabling regulatory ecosystem, while startup practitioners should continue strengthening organizational capabilities, innovation, and knowledge development to enhance business sustainability.

From a methodological perspective, this study contributes to the literature by providing a structured prioritization of the critical success factors for waste management startup development and by revealing the causal relationships among these factors through the integrated DEMATEL-based ANP (DANP) approach. Rather than evaluating critical success factors independently, the proposed DANP framework captures their interdependencies and provides a more comprehensive basis for prioritizing improvement strategies. The findings offer practical guidance for policymakers, entrepreneurs, investors, and other stakeholders in designing strategies that support the sustainable growth of waste management startups in Indonesia.

This study is limited to identifying and prioritizing the critical success factors influencing waste management startup development in Indonesia based on expert judgments. Future research may extend this work by examining the implementation of these factors in practice, evaluating policy interventions, or applying the proposed framework to other sectors or countries to assess its broader applicability.

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