Failure Risk Model of Sustainable Solid Waste Management at The University in Indonesia using Dynamic System Approach

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Abstract

Background - One of the problems encountered by all universities in realizing a sustainable Green Campus is solid waste management due to its complex and dynamic nature, which is known to have the potential risks of failure.

Aim – Application of a dynamic modeling approach with the FMEA and AHP methods to eliminate the risk associated with the inability of universities to process solid waste.

Methods - Data on risk factors and alternative evaluation methods were collected from five experts from various fields.

Results - The results of the risk assessment by experts show some of the highest risk values are associated with Technological Infrastructure, with a risk value of around 900, and the lowest risk is associated with Regulation collisions with a risk value of around 378. The results provided adequate information on the increased risk of each factor from 2019 to 2030 with verified moderate and optimistic conditions models comprising significant values of approximately 0.009 and 0.0273, respectively. This study assists higher education management in decreasing risk failure in the region by creating simulation models that will likely be utilized for scenario analysis in the future. The System Dynamic model's entire approach proved helpful in accomplishing long-term solid waste management in universities. Other dynamic insights that assisted universities improve their knowledge of solid waste management systems.

Research limitations – Further study needs to be conducted in the dynamic model to obtain a more comprehensive and detailed result. This is because the developed model provided an overview that needs further improvement, especially concerning several quantitative data, towards obtaining the adequate method for sustainable solid waste management.

Originality/value – This research used the hybrid method and AHP techniques to analyze solid waste in universities which were developed into a dynamic system model. However, further research is	
needed to enhance this hybrid method.

**Keywords**
Solid waste, risk, systems, dynamics, modeling, sustainability

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1. Introduction
A green campus is described as the coexistence of environmentally conscious practice and education. It is also a location where initiatives are endorsing ecological tenets. This idea was introduced in Europe in the 1990s, with the need to intervene in “any region where human impacts had a negative effect on the environment” acknowledged during the 1992 Rio Earth Summit. Furthermore, it involves the removal of waste food inefficiencies, use of traditional energy sources for regular power needs, as well as proper disposal and efficient recycling programs. Moreover, universities need to establish a timetable for the implementation of these initiatives through solid waste management. This approach has to be integrated into institutional planning to build a clean and green campus.

Presently, there is no clear legislation regulating the waste management activities of tertiary institutions in Indonesia, which poses highly complex threats. Moreover, solid waste management is aimed at minimizing or eliminating threats to human health and the environment. This method is known to work effectively when the process does not threaten human wellness or damage society. Based on this, a sustainable risk management model is needed at universities, thereby adopting a Dynamic Systems approach.

System Dynamics (SD) is a software-based solution used to tackle complex problems in accordance with the predicted time. Moreover, the key to applying this method depends on input, stock, and flow. These factors support the assumptions related to a highly complex process. Additionally, the study carried out by Chaerul and Tanaka (2008) offers a thorough overview of dynamic system applications.

These approaches are considered effective when dealing with certain solid waste management types (Ghisolfi et al., 2017; Rimantho et al., 2020), either in hospitals or developing nations (Chaerul et al., 2008; Kum et al., 2005; Sufian & Bala, 2007). Furthermore, the study carried out by Karavezyris et al. (2002) on an integrated waste management model in Berlin City complements system dynamics through fuzzy logic to address qualitative variables. Based on a small data sample to predict solid waste generation in a fast-growing area, Dyson and Chang (2005) utilized dynamic system modeling. Also, Inghels and Dullaert (2011) developed a similar model to assess the impact of Flemish waste management prevention initiatives. Generally, previous studies only used the dynamic system method to predict potential solid waste generation to serve as a reference for future analysis. However, no research has been carried out in terms of predicting solid waste management process failure.

Based on the recycling activities of solid waste, pollution has been discovered to be complex, uncertain, and rapidly changing, making it impossible for toxic control to be studied and prevented using specific methods. Therefore, a system approach and modeling, which involves combining several methods, such as FMEA, AHP, and System Dynamics, is needed. Also, pollution risk factors are observed as an input in the preparation of solid waste management scenarios. These are also expected to provide future preventive measures. Additionally, risk factor management scenarios are simulated to observe the possibilities of future occurrences through a dynamic system. Besides, specific interventions that aid in realizing an optimal scenario in system objectives are recommended for policy directives.

This study aims to create a complex system model by offering multiple choices, which helps identify the best policies for enhancing sustainable waste management. Moreover, risk management is one of the subjects discussed in this study, as it is a significant element that impacts waste performances. Based on handling changes over time, the dynamic system model was adopted.

2. Methods
This study incorporated qualitative and quantitative analysis in order to evaluate and establish an alternative model. Another, technique known as the dominant-less design was adopted. Furthermore, a specific research methodology and analytical technique, known as the systems thinking approach (Senge, 1994) and dynamic method (Coyle, 1996), were employed.

The primary data were collected by five experienced experts familiar with the potential risks emerging from inadequate solid waste management. Also, the data was obtained from publications containing various related details.

Risk assessment was also analyzed using the Failure Mode Effect Analysis (FMEA) method. The solid waste management risk model was categorized into several groups, namely the technology, social, recycling, regulatory or legal, and waste generation rate sub-models. Meanwhile, the determination of intervention as an alternative solution to optimally reduce risk was adopted. This was carried out by applying the AHP method, using the pairwise comparisons made by the five experts. The application of FMEA and AHP methods also employed the use of questionnaires distributed to seven experienced experts (FMEA (4) and (3) AHP) from indigenous universities. Additionally, the selection of three experts was approved by the Ethic committee from Pancasila University.
Based on the results, the next step was to create a model to identify potential and prospective risk behaviours. This model was constructed through the application of a dynamic system method using the Powersim Studio 2005 Software. A free open-access alternative software that can perform these same functions would be Simantics System Dynamics Version 1.35.0 (http://sysdyn.simantics.org/).

This study focused on the development of possible ideas related to solid waste management through system dynamic analysis, which aims to facilitate (1) the establishment of Causal Loop and Stock Flow Diagrams (CLD & SFD), (2) Leverage analysis, and (3) Scenario specification.

System dynamics were utilized qualitatively and quantitatively. This method is also used as a method of reasoning and understanding to explore its performance qualitatively. However, the system dynamics analysis was transformed into a quantitative simulation and optimization model to help policy development. Moreover, certain assumptions of system discourse led to the adoption of the analytical method. Jay Forrester (the father of system dynamics) described it as “the investigation of information input characteristics (managed), as well as the use of models for the design of improved organizational form and guidance policy” in 1961 (Coyle, 1996).

The qualitative and quantitative dynamic analysis of the Coyle method was used in the following stages,

a. Introduction to the issues- this study aims to explain the problematic failure risk of the waste management process through the use of an input-output diagram.

b. Understanding the problem and descriptive system to systematically better understand the issue by presenting a summary of the solid waste management’s failure risk using Causal Loop Diagram (CLD) and Stock Flow Diagrams (SFD).

c. Qualitative analysis is an effective method for obtaining a deeper understanding of difficult problems.

d. Simulation modeling is the most significant step. Moreover, the conversion of CLD and SFD into this model led to rapid processing and enhancement, and development.

e. Policy Testing and Design were the final steps. This involves the designation and evaluation of policies or scenarios by simulating and adjusting future systems to obtain accurate results.

Verification was carried out by ensuring that the simulation model performed as expected. Based on this reason, a statistical test was carried out to determine whether the components of this model performed as desired. Moreover, the variable that needed to be tested was the time required for the components to exit the processes within the model. This was also carried out to determine if the results were significantly statistically different from the real system’s recorded time. Additionally, verification was carried out by using a 2-sample t-test.

This t-test was used to analyze the hypothesis and calculate the confidence interval of the difference between two population means and the unknown standard deviation (σ). The hypotheses are stated as follows,

\[ H_0: \mu_1 \leq \mu_2 \quad \text{(The actual and modeled risk values are either similar or less)} \]

\[ H_1: \mu_1 > \mu_2 \quad \text{(The actual risk value is greater than the modeled one)} \]

Where \( H_0 \) and \( H_1 \) = the null and alternative hypotheses, \( \mu_1 \) and \( \mu_2 \) = the mean values of the first and second populations, and \( \delta_0 \) = the difference in mean values between the 2 populations tested (Walpole et al., 2007). Statistical testing was carried out using Minitab® 16.1.1 software (Minitab, RRID:SCR_014483). A free open-access alternative software that can perform these same functions would be R (R Project for Statistical Computing, RRID:SCR_001905).

3. Results and discussion
3.1 Results
As earlier mentioned, the risk assessment was carried out by five experts with different backgrounds. The results are shown in Table 1.

Table 1 shows information related to certain failure risks of solid waste management at the University. Based on these results, several sub-factors such as infrastructure, health, safety, and leadership support, and compliance with regulations
had high-risk values of 900, 720, and 729, respectively. Additionally, Table 1 shows that the high-risk values need to be prevented.

Based on this, an alternative was determined through the AHP method. The results of the pairwise comparison assessment are shown in Table 2.

Table 2 provides information on the alternatives, which were observed as the risk reduction intervention program. Based on these results, the improvement of recycling technology, at a weight of 0.429, was regarded as the best. This was accompanied by the development of regulations on solid waste management, participation of the private sector, and campus residents' socialization, with a weight of 0.230, 0.223, and 0.122, respectively.

Based on the immense scope of waste management, the unresolved issue of its failure in universities is a source of concern. Furthermore, it is complicated by several issues, such as lack of environmentally-friendly technologies, inadequate resources, poor leadership support, possible disputes, regional vulnerability, as well as unavailability of recycling facilities and locations. A system dynamic analysis that was focused on model testing and scenario development was adopted to potentially control the problem. According to this system dynamic analysis, the failure risk was referred to as a system. Conversely, the multiple evaluated and risk subsystems were referred to as flow rate and stock level, respectively.
The model testing analysis was also used to determine the system’s leverage by evaluating the compatibility of all subsystems. Using the Powersim Studio 2005 software, a dynamic model was developed and tested. A free open-access alternative software that can perform these same functions would be Simantics System Dynamics Version 1.35.0 (http://sysdyn.simantics.org/). Moreover, the determined subsystems shown in Table 1 were significantly evaluated with the analytical method. These were the variables that impacted the risk mechanism for waste management failure, and therefore, need to be addressed when developing scenarios.

The subsystem was developed due to several discussions and evaluations reported in studies carried out based on strong educational history and familiarity with solid waste management and its risks.

Afterward, the scenario analysis was carried out through the Causal Loop Diagram and Stock Flow Diagrams (CLD & SFD), based on the discussion and risk evaluation outcome. These diagrams were crucial steps adopted in evaluating the system’s leverage, thereby creating several potential scenarios for reducing the likely occurrence of solid waste management failure. The adopted CLD and SFD processes are shown as follows in Figure 1.

Based on Figure 1, the relationship between subsystems and variables related to the CLD demonstrated negativity and positivity (balancing and reinforcing loops). This derivative facilitated the assessment of factors that had a significant impact on the failure risk of the waste management process.

The CLD is used to illustrate the four threats that need to be controlled to protect the environment and human health. These include technical, social, recycling, and policy risks. Moreover, the social, policy, and technological risks, represent contextual relationships. Also, understanding this connectivity in terms of technological risk is based on the fact that “the presence of a technological hazard was highly dependent on compliance with regulations or rules, such as monitoring equipment protection and safety, as well as the creation of technical and non-technical infrastructures.” Additionally, technological use in universities was observed to affect regulatory risk, such as solid waste recycling activities. These were found still to adopt a lot of environmentally unfriendly and straightforward technology while also necessitating regulations on the recycling operation.

The practices that involved several risk factors, such as inadequate working methods and recycling sites, including public tensions and regional vulnerability, had significant social implications. Moreover, the technical factors often affected the risks associated with recycling. Additionally, numerous studies reported that the equipment used for the recycling process was primitive and environmentally unfriendly.

Based on the CLD analysis, a quantitative measure with a sequential description of the risks influencing the scope of waste management failure was observed. The technical factor was also closely linked to the waste management failure.
risk, which resulted in poor environmental quality in universities. Therefore, the possibility of enforcement was discovered to be another support point.

This situation refers to the lack of policies, which promote the use of more environmentally-friendly technologies while still considering workers’ safety (Amoyaw-Osei et al., 2011; Sas et al., 2015). Moreover, one of the shortcomings in developed countries is waste management. This is due to the fact that the construction of service facilities lags behind the availability of disposal infrastructure, which necessitates physical resources, such as land, water, energy, and location,
among others (Porter 1998). The effective recycling of solid waste by processing, smelting, and refining saves costs and helps minimize greenhouse emissions.

The emergence of social risks also impacted the solid waste management process, which is one of the barriers to achieving sustainability. Assefa and Frostell (2007) carried out a study that illustrated the significance of social indicators on solid waste management. Also, Owusu (2010) published a report on the social effects of inadequate waste management. The results of these studies showed that ineffective environmental management had both direct and indirect social implications. Moreover, poor expectations and involvements, public unrest, and regional vulnerability are factors that impacted social aspects (Birhanu & Berisa 2015; Schindler et al., 2012; Oberlin & Szántó 2011).

Law enforcement or compliance is also one of the risk factors that leads to failure in the solid waste management process. Vilas (2015) reported that environmental legislation was ineffectively executed due to a lack of group enforcement. Another reason that led to this failure was policy disputes. According to research carried out by Egwurube (1983), it was reported that one of Nigeria’s environmental conservation agencies had been abolished. This was due to the enactment of incoherent policies within the solid waste management sector. Based on tertiary institutions, data processing also posed a risk. Also, the MSW characterization data availability was the initial crucial step regarding implementing an integrated solid waste management strategy aimed to protect human health and the environment (Oberlin 2013).

Recycling is one of the most efficient strategies for eliminating solid waste because it reduces emissions and also increases economic activity. It has been shown that one of the main reasons for the failure of this process is the lack of expertise and competent staff. Therefore, workers’ willingness to engage in the recycling process is important. This is because they need to be familiar with the practices and proper usage of recycling equipment (Sinha-Khetriwal et al., 2009). Furthermore, inadequate work facilities are another factor that triggers the occurrence of possible failure. This factor has been observed to cause bad operational practices due to a reliance on improvised equipment which is hazardous to the environment. For example, some recycling businesses in Africa, Asia, and Latin America are yet to use appropriate facilities (Sthiannopkao & Wong 2013). Moreover, inefficient recycling processes have resulted in major material and resource losses (Rao 2014). Saphores et al. (2006) revealed that the waste management process also has the potential to trigger the risk of failure.

The relationship between factors that generate risk is greatly triggered by sustainable waste management. However, universities’ active role in implementation needs to be explored further by carrying out SFD research. Moreover, the development of scenario formulations reduces the risk of failure in a waste management system. Additionally, SFD settings were used to assess the system’s leverage.

Based on the preliminary analysis in this research, the risk assessment will start in 2021, and is expected to continue until 2030, as shown in Table 3.

According to Table 3, all variables experienced a growing trend in the probability of solid waste management failure in universities. Furthermore, the social factor had the highest risk growth rate, with a value of 1255 in 2030. This is similar to

Table 3. The risk values based on the SFD model.

| Time | Risk value | Recycling | Regulation | Technology | Social |
|------|------------|-----------|------------|------------|--------|
| 2019 | 0          | 0         | 0          | 0          | 0      |
| 2020 | 2          | 2         | 3          | 2          |        |
| 2021 | 7          | 3         | 8          | 7          |        |
| 2022 | 17         | 5         | 14         | 19         |        |
| 2023 | 34         | 7         | 22         | 42         |        |
| 2024 | 58         | 8         | 32         | 83         |        |
| 2025 | 91         | 10        | 43         | 151        |        |
| 2026 | 134        | 11        | 56         | 254        |        |
| 2027 | 190        | 13        | 71         | 404        |        |
| 2028 | 258        | 15        | 87         | 612        |        |
| 2029 | 339        | 17        | 105        | 891        |        |
| 2030 | 436        | 19        | 125        | 1255       |        |
several previous studies which revealed social factors as one of the contributors to the failure of the waste management process (Assefa & Frostell 2007; Owusu 2010).

Irrespective of the fact that there was an upward trend yearly, the regulatory risk factor did not pose a major risk in 2030, as shown by the model simulation, with a value of 19. Moreover, this demonstrated that the cost of regulatory risk is reasonable. Based on our simulation model performance, the recycling factor with the highest risk growth rate per year is important. Therefore, solid waste management decision-makers need to focus on this aspect based on present trends.

Afterward, a structural suitability test was carried out to determine whether or not the modeled structure contradicted the established awareness of the real system. It was also carried out to ascertain whether or not the main structure of the real system had been modeled. Moreover, the interactions between the components in each subsystem were defined by the structure of the failure risk management model. This was further divided into several sub-models, namely technology, regulation, and social.

3.2 Discussion

According to the simulation results realized using Powersim, the infrastructural, regulatory, and social risk sub-models were displayed an escalation scenario. This fundamental trend shows that they were involved in increasing the reciprocal dominance of sub-factors. Moreover, an escalation scenario tends to occur when two or more parties are involved in a citation, with each subsystem responding to the others. However, assuming the subsystems displaying increased risk were not regulated or eliminated, the competition escalation results in a “lose-lose” situation. Additionally, an in-depth understanding of the processes that potentially pose a threat to other factors or subsystems is one of the best methods to handle this type of situational pattern. Furthermore, a consideration of the existence of delay (delay time) in the implementation phase is critical, as essential activities were likely to be easily avoided or minimized.

Several scenarios were further generated based on the structure suitability test results. These had different policy designs that were implemented in the field under realistic conditions. Moreover, the analytical results of risk and formulated waste management techniques were used to create control scenarios. This research was carried out to plan future strategic measures by enhancing significant risk factors. The best policy was implemented based on the long-term sustainability of solid waste management risk in tertiary institutions. This was carried out after considering the actions of the most profitable model.

Besides, these management scenarios were also focused on the assessments of potential risk factor conditions. Based on the respondents' predictions, these scenarios were unconditionally created in the study area. Afterward, these factors were combined through the respondents' prediction of future variable states. This led to the generation of three scenarios, namely (1) positive, (2) moderate, and (3) current (actual). Additionally, Table 4 shows several scenarios for reducing risk factors.

The model simulation, including all existing intervention results, is shown in Figure 4. The differences in the model-built scenarios in terms of pessimistic, moderate, and optimistic models are also shown in Figure 4. Moreover, the pessimistic scenario was based on the conditions of solid waste management factors, observed to experience failure. This was due to the assumption that the policy was unaltered in the initial scenario (did nothing). However, this was also compared with other alternatives, and it was discovered that several regulations were not better than the current ones. Based on this point of view, observations showed that without any intervention or modification, simulating risk models for electronic waste management factors was impossible, and all risk factors were predicted to increase, within 10 years considerably.

The moderate scenario also suggested that possible future conditions were fully considered under certain circumstances and the capacity of presently owned resources. This setup is dependent on risk factors under the following circumstances, (1) inadequate facilities, (2) recycling locations, (3) data management, (4) leadership support, as well as (5) campus residents' expectations and involvements. Based on this moderate scenario, it was stated that relatively 30% to 50% of the total activity or program was not fully implemented, as shown in Table 4. According to Table 3, the simulation model showed a significant decrease in the risk value.

The model was also enhanced by an optimistic scenario, observed to include other interventions without eliminating the regulatory types. This proves that a legal framework was provided during the implementation of solid waste management. Based on the inclusion of other interventions, better models are likely to be obtained. Moreover, more significant risk reduction values were likely to be achieved, probably in technological innovation and collaboration between actors associated with solid waste management.

Figure 4 shows the simulation results of the waste management risk model, which includes various interventions, such as technological innovation, stakeholder cooperation, and regulatory or legal action. However, technical innovation interventions were included in the technology factor sub-model, responsible for reducing safety and equipment risks.
Also, the system adopted by informal workers remained traditional, as it failed to prioritize the safety and security of the staff. Based on the simulation results, this model proved that interventions in several scenarios lowered the risk value of the legal factors. Therefore, this triggered the previously included risk category. Model integration was used to achieve a better reduction result.

Verification was carried out by ensuring the expected performances of the simulation model were realized. Based on this reason, a statistical test was needed to determine whether the components in the model were executed according to the desired concept. Moreover, the tested variable was the time required for the component to exit the processes within the

| Intervention program                     | Scenario Assumption | Assumption                                                                 |
|------------------------------------------|---------------------|-----------------------------------------------------------------------------|
| Obtaining information on possible waste  | Existing: 0        | Based on the interventions during data collection on possible waste, it was assumed that there are two services. However, they did not participate in the negative situation. In the mild case, one program is implemented. However, it is assumed to intervene in two programs with positive scenarios. |
|                                          | Moderate: 50%       |                                                                            |
|                                          | Optimistic: 50-100% |                                                                            |
| Cultural building with increased visibility | Existing: 0        | The number of measures in the data collection on possible waste is assumed to be three. It did not participate in the negative situation. In the mild case, one program is implemented. However, assuming the whole program intervenes, the scenario is positive. |
|                                          | Moderate: 30%       |                                                                            |
|                                          | Optimistic: 30-100% |                                                                            |
| Technological innovation advancements    | Existing: 0        | The number of measures during the data collection on possible waste is assumed to be three. It failed to participate in the negative situation. In the mild case, one program is implemented. Although, assuming the whole program intervenes, the scenario is positive. |
|                                          | Moderate: 30%       |                                                                            |
|                                          | Optimistic: 30-100% |                                                                            |
| Enhanced regulation and monitoring       | Existing: 0        | The assumption is based on the fact that two programs related to the number of interventions are involved during potential waste data collection. The pessimistic scenario is considered not to interfere, while the moderate one is affected by implementing one program. The scenario is optimistic, assuming it intervenes in two programs. |
|                                          | Moderate: 50%       |                                                                            |
|                                          | Optimistic: 50-100% |                                                                            |

**Figure 4. The difference in simulation results from the three scenarios.**
model. This was also carried out to determine whether the results were significantly similar to that of the real system. In addition, this verification test was carried out using a 2 sample t-test. Statistical testing was carried out using Minitab® 16.1.1 software (Minitab, RRID:SCR_014483). A free open-access alternative software that can perform these same functions would be R (R Project for Statistical Computing, RRID:SCR_001905).

The result showed an average of 1146.83, under the current condition, which was then changed to 898.39, after it was moderately intervened. However, the average was observed at 677.89, after being optimistically intervened. Additionally, a descriptive Pearson correlation resulted in 0.999 in the two intervention models (moderate and optimistic). This further proves that the relationship was extremely close. Based on these results, the values of t-stat for both moderate and optimistic conditions were 3.144 and 2.54306, respectively. These were similar to the paired t-test. Furthermore, the result of the t-table was 2,200, with a p-value of 0.027. Based on the fact that the p-value is less than alpha 5% (t-count> t-table), the decision was rejected H0, which indicates that there was a significant difference between the intervention results of the modeled system.

This showed that the previous studies partially solved the problem of waste management. However, this research had the potential to create new problems. According to certain implications, the potential to reduce the failure risk of the waste management process was indicated due to the implementation of various operating alternatives under moderate and optimistic conditions. This showed that the best alternative solution in waste management was the combination of several approaches into a dynamic system method. Therefore, the results need to be implemented to avoid the risk of failure in waste management. Additionally, the application of this method needs to provide future perspectives related to risk and solid waste management.

4. Conclusions
A System Dynamic model for reducing risk failure in solid waste management in universities was developed and modeled in this research. We contest that the main problem involved in achieving a green campus is solid waste management. Generally, several preliminary studies have been carried out on the partial and incomprehensive risk analysis of solid waste management. Meanwhile, no research has been carried out on the risk factors that threaten this process, such as technology, social, financial, legal, and recycling methods. Furthermore, the failure of the management process was assessed from a variety of perspectives, including technical, regulatory, social, and recycling factors. Each of these aspects contained several subsystems, which were found to be intricately linked. Based on designing simulation models likely used for scenario analysis in the future, this study aids higher education management in reducing risk failure in the area. The full perspective of the System Dynamic model was valuable in achieving sustainable solid waste management in universities. However, other dynamic insights that helped boost knowledge of solid waste management systems in universities were further reported in this study. Based on the results, a moderate and positive scenario, which included multiple risk mitigation program interventions in each aspect, was proposed. Generally, the System Dynamic model functions as an effective decision support system (DSS), for stakeholders involved in solid waste management in universities.

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### Table 5. Comparison of model simulation results in existing, moderate, and optimistic scenarios.

| Time  | Existing | Moderate | Optimistic |
|-------|----------|----------|------------|
| 2019  | 0        | 0        | 0          |
| 2020  | 2        | 0.7      | 0.7        |
| 2021  | 14       | 7        | 7          |
| 2022  | 48       | 25       | 24         |
| 2023  | 117      | 66       | 61         |
| 2024  | 247      | 148      | 133        |
| 2025  | 469      | 298      | 258        |
| 2026  | 829      | 555      | 465        |
| 2027  | 1384     | 980      | 790        |
| 2028  | 2209     | 1657     | 1287       |
| 2029  | 3394     | 2713     | 2021       |
| 2030  | 5049     | 4331     | 3088       |
Data availability

Figshare: FMEA Result.csv.
https://doi.org/10.6084/m9.figshare.14669907

Figshare: AHP Result.csv.
https://doi.org/10.6084/m9.figshare.14669952

This project contains the following underlying data.

- **FMEA Result.csv**: (The results of the FMEA Questionnaire, assessing the risk of failure of the solid waste management process).
- **AHP Result.csv**: (AHP results from the expert assessment related to solid waste management strategy in universities).

Data are available under the terms of the Creative Commons Attribution 4.0 International license (CC-BY 4.0).

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1. The aim of this project is not clearly stated. The study aim “to create a complex system model by offering multiple choices, which helps identify the best policies for enhancing sustainable waste management” is poorly formulated and should be revised significantly. Models are developed to address a specific question which is missing in this manuscript.

2. In the methods section, the first statement “this study incorporates qualitative and quantitative analysis in order to evaluate and establish an alternative model” should be explained. It is very difficult to understand what the authors mean with that statement.

3. What is dominant-less design? The authors should provide some explanation.

4. The methods section is poorly written. The authors were unable to clearly describe what was done in the study. Most of the materials in the results and discussion section should actually be in the methods section.

5. In the “results and discussion” section the authors indicated that “infrastructure, health, safety, and leadership support, and compliance with regulations had high-risk values of 900, 720 and 729, respectively, without providing unit of measurement. It is very difficult to understand what these numbers mean.

6. So far, I am reading the results and discussion section, and I have no idea the relevance of Table 1. This is because the authors were unable to explain what this research is about in the methods section. The presentation of the manuscript requires significant improvement.

7. The paper is not well organised and presented. The authors were unable to explain in the manuscript the causal loop diagram in Figure 1 and the stock and flow diagram in Figure 2. These figures should be moved to the methods section and properly explained with model
equations provided in the appendix for review. Also, the causal loop diagram should help to understand the model structure. After that, the authors should conduct model validation and sensitivity analysis. All these were not done.

8. The results section does not read as results. The authors should refer to other papers to understand how to report results from a modelling and simulation study.

9. This paper is not ready for indexing and needs a complete review to improve quality and readability.

**Is the work clearly and accurately presented and does it cite the current literature?**
No

**Is the study design appropriate and is the work technically sound?**
No

**Are sufficient details of methods and analysis provided to allow replication by others?**
No

**If applicable, is the statistical analysis and its interpretation appropriate?**
No

**Are all the source data underlying the results available to ensure full reproducibility?**
No

**Are the conclusions drawn adequately supported by the results?**
No

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Health systems, heath policy and systems science

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.
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