Quantitative Analysis of Factors for Sustainable Solid Waste Management Systems in Developing Countries Using Structural Equation Modeling

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Abstract

Monitoring and quantifying the sustainability of solid waste management in developing nations is challenging due to complexity and non-availability of a holistic approach in existing research. The present paper addresses this gap by quantifying factors for sustainable waste management from stakeholders' perspectives. A questionnaire is designed to take opinion of experts. The data were collected from 405 respondents and were analyzed using structural equation modeling (SEM). The results of SEM highlighted positive associations among stakeholder involvement, waste management initiatives, and broader sustainability factors, emphasizing interconnectedness. Key factors identified include accessibility to decision-making, community contribution, and technological advancements. It offers insights for policymakers to enhance waste management strategies, promote community engagement, and leverage technology for improved coordination.

Keywords: Sustainability; Solid waste management; Structural equation modeling (SEM); Stakeholder

1. Introduction

Solid waste management (SWM) stands at the forefront of contemporary environmental challenges, representing the comprehensive approach of collecting, disposing, and treating solid waste materials generated by human activities. Due to low waste collection efficiency, incapable reuse and recycling infrastructure, and inefficient SWM practices, a large amount of waste exists in dumpsites and uncontrolled landfills in developing nations [1]. Urbanization and economic growth lead to a rapid and uncontrolled increase in municipal solid waste management generation. Urban waste management system needs to be optimized to stop large-scale environmental contamination from uncollected MSW [2], which, otherwise, will result in the contamination of the environment on a large scale [3]. Conventional garbage disposal techniques put community infrastructure at risk and cause other issues like greenhouse gas emissions, soil damage, groundwater contamination, and air pollution. Adopting a successful and efficient Municipal Solid Waste (MSW) management system guarantees a decrease in handling expenses, including investment, operating, and recycling costs. It enhances the system's sustainability from social, environmental, and economic standpoints [3]. In the context of developing countries, there is an urgent need to adopt the concept of sustainable development while considering waste management. The concept of sustainable development (SD) is strengthened by shifting from conventional linear approach to circular economy (CE) [4].

Due to a lack of financial stability, ineffective technology, and poor technical expertise, municipalities in developing countries have yet to achieve efficient MSW collection services [6,7]. Pokhrel et al.[8] findings on Kolkata municipality, India, stressed the need for an alternative financial models to expand coverage and improve collection efficiency for municipal solid waste, which otherwise ends up in improper dumping and burning of waste at the source. Consumers' willingness to pay for waste-handling services in developing countries is an aspect that has been ignored in the literature. A disproportionate amount of the research on soliciting public preferences also focuses on waste separation at source [9,10] and proper waste disposal [11–13].

Studies examining the public's willingness to increase waste collection efficiency have primarily focused on developed nations [14]. In developing economies, an exponential rise in MSW volume is brought on by urban areas' rapid population development, economic expansion, and rising living standards, all of which have altered urban residents' spending habits [15,16]. The MSW management's institutional capacity and financial stability for responsibly collecting and disposing of waste materials is unable to keep up with the increasing demand [17]. A study conducted on the effective use of technology in Taiwan concluded that inadequate and unreliable public data, robotic automation of processes limitations, and inadequate emergency and prognostic support are considered to be the main obstacles to technological improvement and effective use of technology for sustainable municipal solid waste management [18]. Municipalities must consider achieving technological capacity for sustainable and intelligent performance in municipal solid waste management systems [19,20].

Structural equation modeling (SEM) is a reliable method for defining and conceptualizing the relationship between system components widely utilized in behavioral science research [21]. Observed variables, which may be measured directly, and latent variables, whose existence is inferred from observations, are the elements or variables that are typically included in a structural equation model [22]. SEM is applied for understanding the factors influencing recycling behavior in Taiwan college students [23], the effect of a campaign of the plastic bag use reduction policy toward "green behavior" of Bogor City society, Indonesia.[24], Canadian customers' pro-environmental behavior [25]; in Sri Lanka, attitudes and perceptions toward improved solid waste management techniques [26]), assess the recycling habits of housewives in Turkey [27].

1.1. Problem Statement

The sustainable management of solid waste is a complex and multidimensional challenge, intricately connected to economic, technical, environmental, institutional, and social dimensions. While existing studies have acknowledged the importance of these factors, a critical gap in understanding their interplay and quantifying their impact on the overall sustainability of solid waste management (SSWM) systems, particularly in the context of developing nations still exists.

Existing metrics for assessing sustainability in solid waste management often fall short of capturing the multidisciplinary nature of the issue. A holistic and quantifiable approach is necessary to formulate effective strategies and policies for fostering sustainable waste management practices in developing nations. Researchers have struggled to provide a unified metric for assessing sustainability, hindering the development of targeted interventions.

This study addresses these gaps by thoroughly examining the intricate relationships among key variables within the proposed framework. Through Structural Equation Modeling (SEM) analysis, the research seeks to identify and quantify the factors that contribute to the sustainability of solid waste management systems, with a specific focus on stakeholders' perspectives. By doing so, this study aims to provide a robust foundation for developing a hierarchy of sustainability criteria that can guide the formulation of evidence-based strategies and policies.

1.2. Hypotheses Development

This study proposes a comprehensive framework for sustainable solid waste management (SSWM). Three latent variables are identified: SSWM, stakeholder involvement (SI), and solid waste management initiatives (SWMI). Hypotheses 1-5 posit a positive influence of economic, technical, environmental, institutional, and social indicators on SSWM. Hypotheses 6-10 suggest that intensified stakeholder involvement positively affects SWM system effectiveness. Hypotheses 11-22 propose that various indicators collectively contribute to the success of SW management initiatives. Additionally, Hypotheses 23-24 state that stakeholder involvement influences both SSWM and SWMI. Finally, Hypothesis 25 suggests that SWMI positively influences SSWM, emphasizing the role of effective waste management initiatives in overall sustainability.

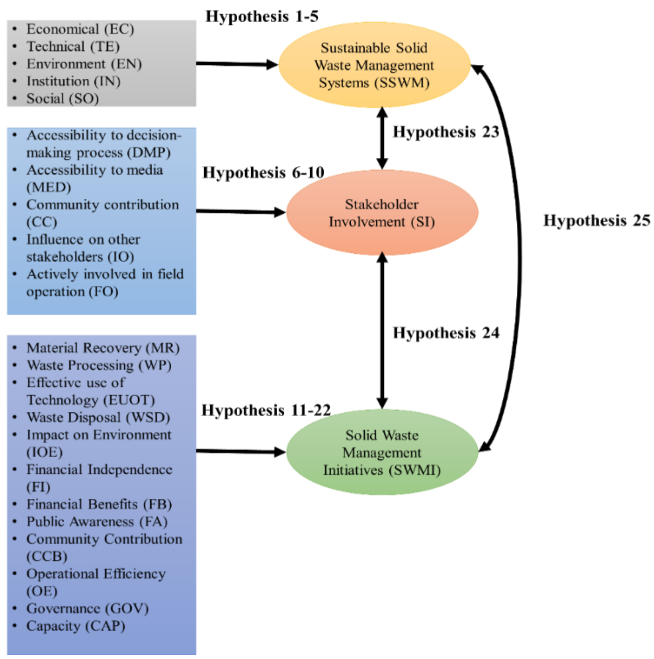

Figure 1. Conceptual model

2. Methodology

2.1. Data collection

An extensive literature analysis was the foundation for developing an initial questionnaire, which was then improved through an iterative critical examination process during researcher meetings and contacts with various stakeholder groups. A preliminary questionnaire was designed based on identified risk and success factors affecting the sustainability of solid waste management. For survey-based research, [28] suggested 10–30 respondents for survey-based research. We conducted a pilot study on 25 participants, including field experts, researchers, and the general public. In a face-to-face interview, the respondents carefully examined the draft of the created questionnaire—the pilot study aimed to evaluate the questionnaire's comprehensiveness and relevance. The valuable feedback regarding the in-depth understanding of the topic, the duration required to fill out the questionnaire, the exclusion of unnecessary questions, and the addition of any missing information were all fully incorporated. This information, on the one hand, helped finalize the questionnaire with minor changes and facilitated the identification of the target group for the questionnaire response.

The final questionnaire was distributed via Google Forms, emails, post mail, and personal meetings with the respondents. The target for response was set to 398 based on available research, keeping the population of our target area in mind. Moreover, two separate meetings with sanitation experts and field visits to the concerned sanitation departments were part of the process. While responding to the survey, it was ensured that the stakeholders were adequately educated to understand the terminologies and questions before providing a representative answer. This was ensured through a brief interactive session and introduction of the research study and its significance before conducting the survey.

2.2. Questionnaire design

The designed questionnaire is divided into three sections:

1. The first section dealt with respondents' personal information such as Name, Occupation, Designation, Experience Organization, email, and age.
2. The second section deals with the ranking of five elements of sustainability in terms of stakeholder's preferences.
3. The third concerns the influence of the stakeholder's weightage (importance) in decision-making, accessibility to media, community contribution, influence on other stakeholders, and involvement in solid waste management-related field operations.
4. The fourth section lists the factors and allows the stakeholders to rank each factor on a Likert scale from a weaker endorsement (i.e. 1) of each factor to a stronger endorsement of the factor (i.e. 5). The intermediate range followed was low (2), moderate (3), and high (4), based on the participants' preferences and experience. Based on human working memory capacity, most researchers only suggest a five point Likert scale [29].

2.3. Respondent selection

The target group for the questionnaire response includes Experts from municipalities responsible for waste handling activities, Engineers, Health professionals, Academia, Finance, Freelancers, Non-government organizations, Students, and the General public. For a population of Peshawar 2,412,000, as of 2023 census data (https://www.pbs.gov.pk/), with a confidence interval of 5 and a confidence level of 95%, the sample size required was 384. A total of 650 questionnaires were distributed, and 405 responses were received. Thus, a response rate of 69.55% was achieved. The average response rate is above 50%, which is adequate for surveys [30].

2.4. Structural equation modeling (SEM)

A systematic approach has been undertaken for structural equation modeling (SEM), beginning with confirmatory factor analysis (CFA) to validate the measurement model by confirming that observed variables align with their intended latent constructs. The reliability of the measurement model was assessed through metrics like Cronbach's alpha or composite reliability, ensuring that indicators consistently measure their respective latent constructs. Convergent validity analysis is conducted to evaluate the relationships among indicators of the same latent construct, aiming for high convergent validity to signify coherence. Discriminant validity is scrutinized using the Heterotrait-Monotrait (HTMT) Ratio of Correlations, ensuring the distinctiveness of latent constructs. The overall fit of the structural equation model is gauged through various fit indices such as Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Bentler-Bonett Non-normed Fit Index (NNFI), Relative Noncentrality Index (RNI), Bentler-Bonett Normed Fit Index (NFI), Bollen's Relative Fit Index (RFI), Bollen's Incremental Fit Index (IFI) and Parsimony Normed Fit Index (PNFI), providing a comprehensive evaluation of model fit. Estimated regression coefficients (β) explained the strength and direction of relationships between latent constructs and observed variables. Additionally, R^2 values are examined to understand the proportion of variance explained in latent variables. This thorough analysis ensures a rigorous evaluation of the SEM, allowing for interpretation of results and iterative refinement of the model as necessary based on statistical outcomes and theoretical considerations.

3. Results and Analysis

3.1. Confirmatory factor analysis (CFA).

The primary step in structural equation modeling (SEM) is confirmatory factor analysis (CFA). CFA helps assess the similarity between chosen indicators and their respective latent constructs. The model's fitness is evaluated using loading, Cronbach's Alpha, Composite Reliability, and Average Variance Extracted (AVE), ensuring the measurement model's internal consistency and convergent validity.

Table 1 shows the latent variables and their respective indicators influencing sustainable solid waste management systems. As all loading values exceed 0.4 [31], no indicators are removed from the study. The sustainable solid waste management systems (SSWM), the latent variables of economical (EC), technical (TE), environment (EN), institution (IN), and social (SO) show positive associations with the loading of 0.410, 0.523, 0.577, 0.552, and 0.588, respectively. These estimates are accompanied by high Z-scores ranging from 8.19 to 12.22, reflecting their statistical significance (all p-values < 0.001). The latent variable stakeholder involvement (SI) reveals strong positive associations, with loading ranging from 0.601 to 0.929 for indicators such as accessibility to the decision-making process (DMP), accessibility to media (MED), community contribution (CC), influence on other stakeholders (IO), and actively involved in a field operation (FO). The associated Cronbach's Alpha values, ranging from 0.83 to 0.9, indicate high internal consistency as it is higher than the threshold value of 0.7 suggested by Brown [32], while composite reliability values above 0.8 signify reliability exceeding the threshold value of 0.7 suggested by Hair et al. [31]. The latent variables under solid waste management initiatives (SWMI) also demonstrate positive associations, with loading ranging from 0.429 to 0.764. Notably, the indicators material recovery (MR), financial independence (FI), and operational efficiency (OE) exhibit high reliability with Cronbach's Alpha values of 0.9, 0.76, and 0.92, respectively. The composite reliability values, exceeding 0.8, reinforce the reliability of the latent variables. Additionally, average variance extracted (AVE) values ranging from 0.4 to 0.55 affirm convergent validity for most latent variables. AVE value of 0.4 can be accepted despite being lower than the threshold value of 0.5 if the CR value is higher than 0.6, as suggested by Fornell and Larcker [33]. In summary, these results emphasize the complex nature of sustainable waste management, highlighting the significance of economic, technical, environmental, institutional, and social factors, stakeholder involvement, and specific waste management initiatives. The high reliability and convergent validity of the measurement constructs enhance the robustness of the study's findings.

Table 1. Confirmatory factor analysis, reliability, and convergent analysis

Latent variable	Indicator	Loading	Z	p-value	Cronbach's Alpha	Composite Reliability	Average Variance Extracted (AVE)
Sustainable solid waste management systems (SSWM)	EC	0.410	8.19	< .001	0.72	0.71	0.4
	TE	0.523	10.92	< .001			
	EN	0.577	11.36	< .001			
	IN	0.552	11.86	< .001			
	SO	0.588	12.22	< .001			
Stakeholder involvement (SI)	DMP	0.919	13.54	< .001	0.83	0.82	0.55
	MED	0.601	11.51	< .001			
	CC	0.826	17.1	< .001			
	IO	0.882	17.82	< .001			
	FO	0.929	16.97	< .001			
	MR	0.581	13.13	< .001	0.9	0.92	0.5

Solid Waste Management Initiatives (SWMI)	WP	0.662	15.95	< .001
	EUOT	0.687	15.84	< .001
	WSD	0.647	13.76	< .001
	IOE	0.429	9.2	< .001
	FI	0.585	12.28	< .001
	FB	0.598	12.36	< .001
	FA	0.763	15.4	< .001
	CCB	0.765	15.83	< .001
	OE	0.684	16.33	< .001
	GOV	0.764	17.04	< .001
	CAP	0.712	15.8	< .001

3.2. Heterotrait-Monotrait (HTMT) ratio of correlations

The Heterotrait-Monotrait (HTMT) ratio of correlations offers valuable insights into discriminant validity by comparing the correlations between different latent constructs with the correlations within the same latent construct. In the context of this study, the HTMT ratios are presented in the correlation matrix, as shown in Table 2, and their values should be less than 0.9 [34].

The HTMT ratios between SI and SSWM are 0.518. This indicates that the correlation between these two constructs is significantly lower than the threshold value of 0.9. This suggests reasonable discriminant validity between stakeholder involvement and the broader factors influencing waste management. Similarly, for SWMI, the HTMT ratio is 0.555 when compared to SSWM, signaling good discriminant validity.

Table 2. Discriminant validity using the heterotrait-monotrait ratio of correlations (HTMT) ratio

Latent	SI	SWMI	SSWM
SI	1	0.518	0.233
SWMI	0.518	1	0.555
SSWM	0.233	0.555	1

3.3. Model fit indices

The model fit indices, including Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Bentler-Bonett Non-normed Fit Index (NNFI), Relative Noncentrality Index (RNI), Bentler-Bonett Normed Fit Index (NFI), Bollen's Relative Fit Index (RFI), Bollen's Incremental Fit Index (IFI) and Parsimony Normed Fit Index (PNFI), collectively indicate an excellent fit of the structural model to the observed data as shown in Table 3. The values exceeding the threshold of 0.90 [35] signify a high level of agreement between the hypothesized model and the actual data. This solid fit underscores the validity of the proposed relationships among latent constructs and their indicators, enhancing the overall robustness of the SEM. The CFI is 0.993, TLI is 0.992, NNFI is 0.992, and RNI is 0.993, all well above the 0.95 threshold, providing strong evidence for the model's goodness of fit. Additionally, the NFI, RFI, IFI, and PNFI further contribute to the model's robustness, with NFI at 0.981, RFI at 0.979, IFI at 0.993 and PNFI at 0.875, supporting the adequacy of the model in explaining the observed data.

Table 3. Model fit indices

	Model
Comparative Fit Index (CFI)	0.993
Tucker-Lewis Index (TLI)	0.992
Bentler-Bonett Non-normed Fit Index (NNFI)	0.992
Relative Noncentrality Index (RNI)	0.993
Bentler-Bonett Normed Fit Index (NFI)	0.981
Bollen's Relative Fit Index (RFI)	0.979
Bollen's Incremental Fit Index (IFI)	0.993
Parsimony Normed Fit Index (PNFI)	0.875

3.4. Structural model assessment

The structural model assessment examines the estimated regression coefficients (β), their 95% confidence intervals, and the R^2 values for each latent variable. It provides a comprehensive understanding of the model's reliability and explanatory power, as summarized in Table 4 and Figure 2.

In the stakeholder involvement (SI) latent variable, the regression coefficients for indicators such as accessibility to decision-making process (DMP) ($\beta = 0.664$, 95% CI [0.596, 0.732], $z = 12.91$, $p < 0.001$), accessibility to media (MED) ($\beta = 0.597$, 95% CI [0.52, 0.674], $z = 12.91$, $p < 0.001$), community contribution (CC) ($\beta = 0.802$, 95% CI [0.746, 0.857], $z = 16.2$, $p < 0.001$), influence on other stakeholders (IO) ($\beta = 0.832$, 95% CI [0.782, 0.883], $z = 16.82$, $p < 0.001$), and actively involved in field operation (FO) ($\beta = 0.788$, 95% CI [0.738, 0.839], $z = 17.41$, $p < 0.001$) are all positive and statistically significant. The R^2 values, ranging from 0.357 to 0.693, indicate that the latent variable effectively explains a substantial portion of the variability in these indicators. The significant associations, precise estimates, and high R^2 values collectively suggest that the model successfully captures the relationships between stakeholder involvement and its contributing factors.

Within the solid waste management initiatives (SWMI) latent variable, the regression coefficients and associated confidence intervals for indicators like material recovery (MR) ($\beta = 0.651$, 95% CI [0.589, 0.713], $z = 20.2$, $p < 0.001$), waste processing (WP) ($\beta = 0.767$, 95% CI [0.719, 0.815], $z = 20.2$, $p < 0.001$), effective use of technology (EOT) ($\beta = 0.747$, 95% CI [0.696, 0.798], $z = 18.36$, $p < 0.001$), waste disposal (WD) ($\beta = 0.694$, 95% CI [0.631, 0.757], $z = 16.34$, $p < 0.001$), impact on environment (IOE) ($\beta = 0.517$, 95% CI [0.436, 0.597], $z = 10.7$, $p < 0.001$), financial Independence (FI) ($\beta = 0.625$, 95% CI [0.561, 0.689], $z = 15.7$, $p < 0.001$), financial benefits (FB) ($\beta = 0.636$, 95% CI [0.565, 0.708], $z = 13.51$, $p < 0.001$), public awareness (PA) ($\beta = 0.755$, 95% CI [0.701, 0.809], $z = 17.38$, $p < 0.001$), community contribution (CC) ($\beta = 0.746$, 95% CI [0.696, 0.797], $z = 18.53$, $p < 0.001$), operational efficiency (OE) ($\beta = 0.747$, 95% CI [0.7, 0.795], $z = 18.24$, $p < 0.001$), governance (GOV) ($\beta = 0.778$, 95% CI [0.732, 0.825], $z = 19.36$, $p < 0.001$), and capacity (CAP) ($\beta = 0.736$, 95% CI [0.684, 0.788], $z = 17.62$, $p < 0.001$) are all positive and statistically significant. The R^2 values, ranging from 0.423 to 0.606, highlight the effectiveness of the latent variable in explaining the observed variability in these indicators. This suggests that the model adequately represents the relationships between solid waste management initiatives and their contributing factors.

For the latent variable "sustainable solid waste management systems," the regression coefficients and confidence intervals for indicators such as economical (EC) (β = 0.492, 95% CI [0.391, 0.592], technical (TE) (β = 0.649, 95% CI [0.565, 0.733], z = 8.09, p < 0.001), environment (EN) (β = 0.631, 95% CI [0.541, 0.722], z = 8.47, p < 0.001), institution (IN) (β = 0.643, 95% CI [0.56, 0.726], z = 7.83, p < 0.001), and social (SO) (β = 0.657, 95% CI [0.578, 0.735], z = 8.73, p < 0.001) are all positive and statistically significant. The R^2 values, ranging from 0.242 to 0.431, indicate that the latent variable explains a significant proportion of the observed variability in these broader factors influencing sustainable waste management. This reinforces the model's ability to capture the relationships between these factors.

Table 4. Structural model assessment

Latent	Indicators	Estimate	β	95% Confidence Intervals		z	p-value	R^2	Hypothesis Remarks
				Lower	Upper				
SI→	DMP	1	0.664	0.596	0.732			0.441	Accepted
	MED	0.9	0.597	0.52	0.674	12.91	< .001	0.357	Accepted
	CC	1.208	0.802	0.746	0.857	16.2	< .001	0.643	Accepted
	IO	1.254	0.832	0.782	0.883	16.82	< .001	0.693	Accepted
	FO	1.188	0.788	0.738	0.839	17.41	< .001	0.621	Accepted
SWMI→	MR	1	0.651	0.589	0.713			0.423	Accepted
	WP	1.179	0.767	0.719	0.815	20.2	< .001	0.589	Accepted
	EUOT	1.148	0.747	0.696	0.798	18.36	< .001	0.558	Accepted
	WD	1.067	0.694	0.631	0.757	16.34	< .001	0.482	Accepted
	IOE	0.794	0.517	0.436	0.597	10.7	< .001	0.267	Accepted
	FI	0.961	0.625	0.561	0.689	15.7	< .001	0.391	Accepted
	FB	0.978	0.636	0.565	0.708	13.51	< .001	0.405	Accepted
	PA	1.16	0.755	0.701	0.809	17.38	< .001	0.57	Accepted
	CCB	1.147	0.746	0.696	0.797	18.53	< .001	0.557	Accepted
	OE	1.148	0.747	0.7	0.795	18.24	< .001	0.558	Accepted
	GOV	1.196	0.778	0.732	0.825	19.36	< .001	0.606	Accepted
	CAP	1.131	0.736	0.684	0.788	17.62	< .001	0.542	Accepted
SSWM→	EC	1	0.492	0.391	0.592			0.242	Accepted
	TE	1.321	0.649	0.565	0.733	8.09	< .001	0.422	Accepted
	EN	1.284	0.631	0.541	0.722	8.47	< .001	0.398	Accepted
	IN	1.308	0.643	0.56	0.726	7.83	< .001	0.414	Accepted
	SO	1.335	0.657	0.578	0.735	8.73	< .001	0.431	Accepted

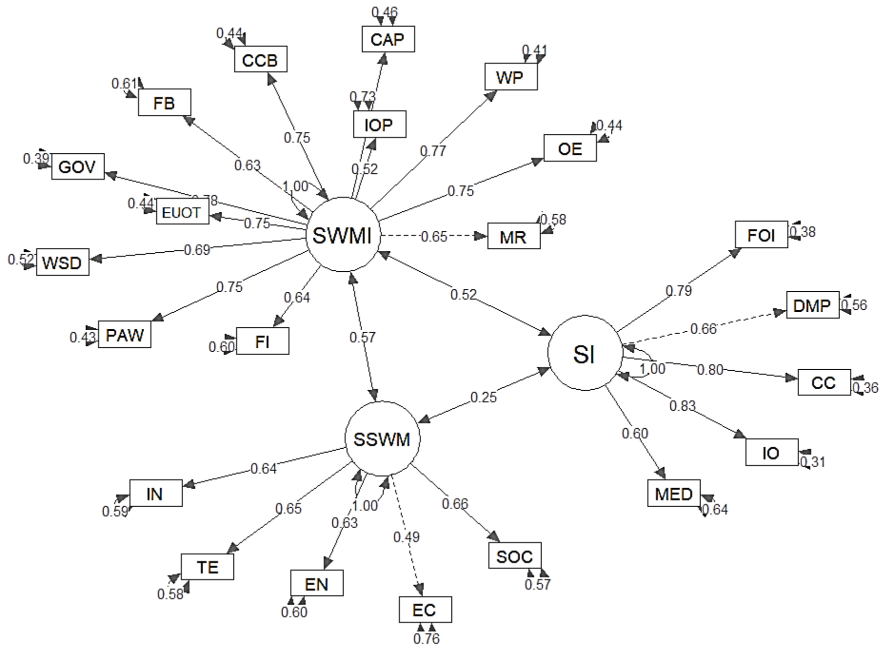

Figure 2. SEM model

3.5. Path Analysis

The regression coefficients (β) and associated 95% confidence intervals provide further insights into the relationships between latent variables in the structural equation model, specifically the directional pathways between stakeholder involvement (SI), solid waste management initiatives (SWMI), and factors responsible for sustainable solid waste management systems (SSWM) as shown in Table 5.

The positive estimate of 0.254 for the pathway from SI to SSWM indicates a statistically significant and positive impact. As stakeholder involvement increases, there is a corresponding increase in the factors contributing to sustainable waste management practices. The narrow confidence interval (0.142 to 0.366) further emphasizes the precision of this positive relationship.

Similarly, the pathway from SI to SWMI is also positively significant, with an estimated 0.517. This implies that higher levels of stakeholder involvement are associated with increased emphasis on solid waste management initiatives. The confidence interval (0.432 to 0.602) reinforces the reliability of this positive association.

Furthermore, the pathway from SWMI to SSWM has a positive estimate of 0.565. This indicates that as the focus on solid waste management initiatives increases, there is a corresponding positive impact on the broader factors contributing to sustainable waste management. The confidence interval (0.471 to 0.66) once again emphasizes the statistical significance of this relationship.

Table 5. Path analysis

Paths	Estimate	β	95% Confidence Intervals		Z	p	Hypothesis Remarks
			Lower	Upper			
SI→ SSWM	0.0829	0.254	0.142	0.366	3.71	< .001	Accepted
SI→SWMI	0.2233	0.517	0.432	0.602	8.7	< .001	Accepted
SWMI→SSWM	0.1809	0.565	0.471	0.66	6.49	< .001	Accepted

4. Discussions

The SEM results comprehensively understand the complex interplay of factors influencing sustainable solid waste management systems. The precision in loading, positive associations among latent variables, and robust model fit collectively contribute to a compelling narrative that underscores the significance of stakeholder involvement, specific waste management initiatives, and broader factors responsible for sustainable waste management.

The positive associations identified in stakeholder involvement, solid waste management initiatives, and broader sustainability factors offer actionable insights for policymakers, waste management professionals, and community stakeholders.

The identified positive impact of factors such as accessibility to the decision-making process, community contribution, and active involvement in field operations on stakeholder involvement suggests that fostering open decision-making processes, encouraging community participation, and actively engaging stakeholders in field operations can lead to more effective waste management systems. Policymakers and waste management authorities may consider implementing strategies that enhance accessibility to decision-making processes, encourage community participation through awareness campaigns and community outreach programs, and involve stakeholders in the actual operations of waste management.

In the context of solid waste management initiatives, the positive associations with indicators like waste processing, effective use of technology, and public awareness imply that investing in advanced waste processing technologies, leveraging technology for efficient waste management, and promoting public awareness campaigns can significantly contribute to the success of waste management programs. Moreover, allocating resources to research, develop, and implement innovative waste processing technologies and incorporating digital solutions for better waste management coordination could be practical steps.

Furthermore, the positive impacts identified in factors responsible for sustainable waste management, particularly in technical and institution, emphasize the importance of incorporating advanced technologies and robust governance structures into waste management policies. Policymakers and waste management authorities may find it beneficial to invest in training programs for adopting technology-driven solutions, establishing effective governance mechanisms, and promoting environmentally conscious practices.

From a community-oriented perspective, the positive association with society highlights the importance of community-centric approaches to waste management. Initiatives that involve communities in the planning, decision-making, and execution of waste management strategies can enhance the overall effectiveness and sustainability of such programs.

The results of path analysis showed a positive and statistically significant impact of stakeholder involvement on both solid waste management initiatives and broader sustainable waste management practices, emphasizing the importance of actively engaging various stakeholders. To translate these findings into action, organizations and policymakers should establish effective communication channels, conduct awareness campaigns, and involve stakeholders in decision-making processes. Moreover, the positive association between stakeholder involvement and solid waste management initiatives highlights the need for continued investment in projects focusing on waste reduction, recycling, and public education. Underlining these initiatives contributes to sustainable waste management and reinforces the positive impact on broader sustainability factors. As a practical step, policymakers should consider incorporating the implications of these SEM results into waste management policies, incentivizing businesses and communities to participate actively in waste management efforts. Continuous monitoring and evaluation of initiatives, along with education and collaboration among stakeholders, are essential for the ongoing success of sustainable waste management practices. By adopting these steps, communities, and organizations can work collaboratively to build resilient waste management systems that benefit the environment and society.

5. Conclusions

Utilizing Structural Equation Modeling (SEM), this study revealed key insights for enhancing sustainable solid waste management. Stakeholder involvement was found to impact waste initiatives and broader sustainability positively. Open decision-making processes, community engagement, and stakeholder participation are crucial. Additionally, investments in innovative waste processing technologies, technology use, and public awareness were identified as practical strategies. Policymakers are urged to integrate these findings, emphasizing community-centric approaches, governance structures, and environmentally conscious practices. Continuous monitoring, stakeholder collaboration, and targeted interventions are essential for building resilient waste management systems that benefit the environment and society. This study provides a valuable framework for evidence-based policies and actions in the pursuit of sustainable waste management.

Future research is suggested to examine the subjectivity, stakeholder input, and synthesized relative priorities or weights for the various solid waste management sustainability factors. Replicate the stakeholder survey, paying particular attention to sub-factors. The relative importance of the factors and sub-factors will ultimately lead to the development of a suggested framework that will function as a thorough, practice-focused instrument for assessing the sustainability of solid waste management systems in developing countries.

Conflicts of Interest: The authors declare no conflict of interest.

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