

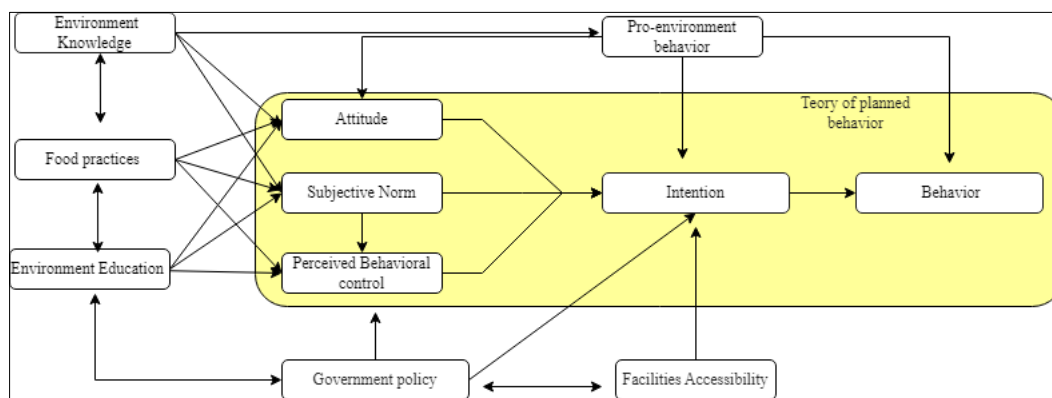
Perspective and modeling requirement on household solid waste management

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Highlights:

- A novel conceptual model integrates food practices into the Theory of Planned Behavior (TPB) to explain household solid waste generation.
- The Analytical Hierarchy Process (AHP) reveals pro-environmental behavior, government policy, and attitude as the most influential factors.
- Provides a decision-support framework for policymakers to design targeted, sustainable household waste management strategies.

Abstract

Rapid economic and population growth, urbanization, and resource overexploitation have intensified household solid waste generation, creating serious environmental challenges, particularly in developing countries. Despite various efforts, waste management systems remain inadequate, hindered by poor infrastructure, limited recycling practices, and insufficient disposal facilities. However, existing models often overlook the behavioral dimension of waste generation. This study aims to identify and assess critical factors influencing the development of effective household waste management by integrating food practices into the Theory of Planned Behavior (TPB), thereby addressing a significant theoretical gap. A systematic literature review of 78 peer-reviewed articles published between 2014 and 2024 was conducted to extract key influencing factors and conceptual models. The created model concept will be evaluated using the Analytical Hierarchy Process (AHP) based on expert judgment to determine the relative importance of each variable. Five experts were selected using purposive sampling from four stakeholder entities: academia, government, industry, and community. The analysis revealed 11 interrelated factors, with pro-environmental behavior (23.8%), government policy (18.7%), and public attitude (14.8%) emerging as the most influential. The findings highlight that behavioral change, supported by robust policy frameworks, is essential for enhancing household-level waste management. This study offers a comprehensive decision-support model that integrates behavioral, institutional, and technological interventions, providing actionable insights for policymakers and practitioners in promoting sustainable consumption and waste reduction practices.

Keywords: Analytical hierarchy process (AHP); Food practices; Household solid waste

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1. Introduction

Household solid waste has emerged as a significant concern, both nationally and globally, particularly in developing nations. The household sector is the predominant source of waste, presenting a challenge across both developing and developed countries [1], [2]. Daily activities generate household waste, typically comprising 41% organic and 69% non-organic components [3], [4], [5]. Effective household waste management encompasses collection, transportation, and processing [6], yet its implementation necessitates the coordination of multiple sectors and stakeholders exhibiting diverse behavioral patterns [7]. Escalating waste, reflecting growth, industrialization, and population, demands comprehensive management mapping of regulations, environmental impacts, and prevention strategies [8].

The environment and community organizations influence household waste management with a focus on collection, transportation, and processing [9], [10]. Community participation in waste selection is influenced by the community's behavioral, cognitive, attitudinal, and situational factors [11]. These are important in mitigating negative impacts and environmental problems [12]. Furthermore, by building a model framework, the household waste management system becomes the main point of the strategy in modeling the relationship of consequences from each sector [13]. The management system begins after household waste is produced by looking at the relationship between intention and waste sorting behavior [14]. One of the basic measurement model parameters uses the theory of planned behavior [15], [16], [17], [18] and the norm activation model to model the influence of social behavior on household waste selection and recycling.

Modern technologies, such as the Internet of Things (IoT), facilitate the monitoring of waste collection, sorting, transportation, and processing [19]. However, these technological solutions often neglect upstream behavioral determinants, notably food practices contributing to waste generation. Optimizing household waste management system designs can lead to reduced investment, operational, and recycling costs, improving overall environmental and socio-economic sustainability [20]. Additionally, multi-agent simulation and dynamic system models are effective for analyzing factors influencing waste disposal facility selection [21]. A key starting point for waste disposal decision-making lies within the household community, acknowledging the diverse access to waste disposal options [22].

While behavioral models like the Theory of Planned Behavior (TPB) or the Norm Activation Model (NAM) extensively explain household waste management and the environment [23], few studies address (shopping planning, preparation, storage, cooking, eating behavior, and leftovers management). These practices are key behavioral contributors to waste generation, highlighting a significant research gap. This study addresses this gap by integrating food practices as a novel variable into the TPB framework, thereby enhancing the explanatory power of existing behavioral models in household solid waste management. This integration offers a more comprehensive understanding of daily decision-making that influences household waste, particularly in developing countries.

Therefore, this study aims to develop a conceptual model of household solid waste management behavior by integrating food practices into the theory of planned behavior (TPB), followed by a model assessment process utilizing the analytical hierarchy process (AHP). Based on this objective, the research addresses two key questions: How can a food practice model be constructed for integration into behavior-based waste management and how can a model assessment identify the dominant factors influencing household solid waste.

1.1. Food Practices and the Complexity of Waste Formation

Research on the effectiveness of household waste management, especially public participation, waste sorting, and environmental awareness, is an important factor in the success of waste reduction initiatives [24], [25], [26], [27]. Despite various efforts, sustainable household waste management remains a persistent global challenge, necessitating both technological innovations and integrated, multidimensional approaches [28], [29], [30]. The incorporation of technological processes such as composting, anaerobic digestion, and incineration plays a vital role in enhancing environmental outcomes and increasing processing efficiency [31], [32]. Among the components of household solid waste, kitchen waste represents a substantial fraction and poses serious environmental implications due to its organic and biodegradable nature [33], [34]. However, the field of food practice still requires a comprehensive understanding of planning, purchasing, preparation, consumption, and storage, contributing to the formation of organic and non-organic waste [35], [36].

While several studies have explored food waste reduction strategies [37] and technological adoption within households [38], [39], a critical gap remains in the literature concerning the complex interrelationship between individual food practices and household waste generation patterns. Research has been conducted to examine daily routines and behavioral patterns related to food waste at the household level [40], [41], [42], [43]. Research is needed to explore how food practices, such as procurement, preparation, consumption, and storage, directly impact waste quantity and type. Existing research often focuses on general waste formation patterns or community behavioral interventions [44], [45], [46], [47] however, not conduct an in-depth analysis of daily routines and decisions in the formation of kitchen waste. The literature gap highlights the need for qualitative and quantitative investigations on food practices and kitchen waste for developing more targeted and effective waste reduction strategies in the context of global sustainability efforts.

2. Material and Methods

2.1. Systematic Literature Review

A systematic literature review was developed to comprehensively understand the topic, guided by the research implementation process [47], [48] through several stages, including planning, implementation, and reporting of observation results [49]. The planning process identified objectives, research questions, and observation steps. The article observation implementation was carried out by identifying and selecting primary sources, collecting data sources, and analyzing and integrating search data. The final stage was writing the article observation results, then providing a comprehensive description.

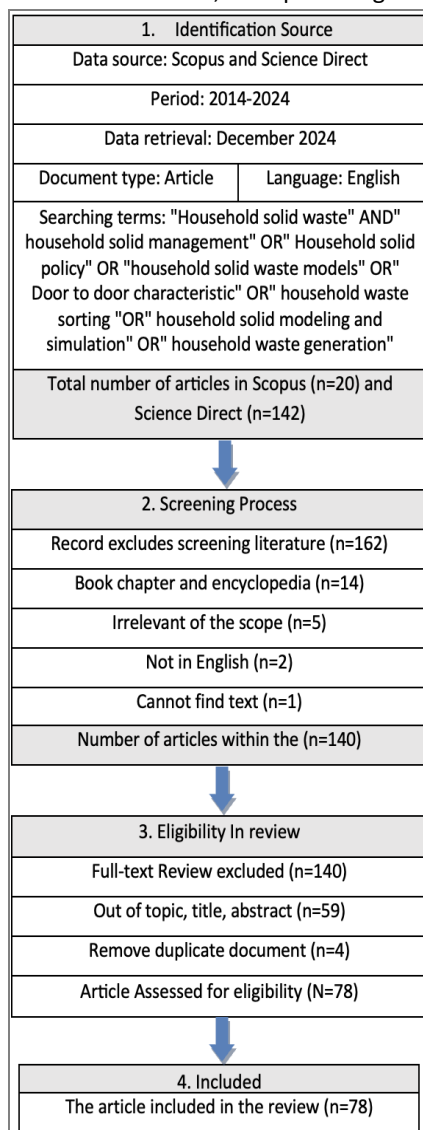
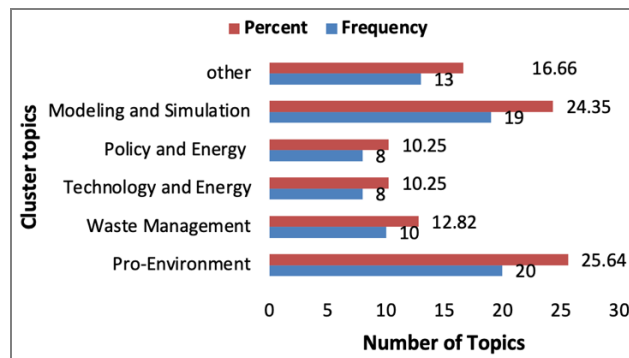


Figure 1.
Flow of studies
systematic literature
review

This research focused on identifying household waste management models in developing countries. The first step was to search for English-language articles in digital databases with publication dates from 2014 to 2024. The article search was conducted in December 2024. Next, 162 articles were obtained from the Scopus and ScienceDirect digital databases. The second step was to examine inclusion and exclusion criteria, including non-English language articles for standardization and ease of data analysis, book chapters, and encyclopedias due to their focus on primary research articles, and articles lacking full text despite institutional access verification to ensure the availability of complete source material. The inclusion and exclusion process of articles resulted in 140 articles that met the scope of the literature review criteria. The third step was to review each article that met the identification criteria. The scope of the article information analysis was classified using the following criteria: purpose, methodology, abstract, systematic depth, time period, and research topic. A total of 78 articles met these criteria, so they could be used as baseline data for in-depth article observation to determine the development of modeling in household waste management. **Figure 1** explain study flow, systematic literature review.

Figure 1 explains the steps of a systematic literature review, from collecting to filtering publications relevant to the topic. In stage 4, articles included is the number of articles that will be synthesized to determine publication trends, research trends, methodology, focus, and future research. The articles reviewed range from 2014 to December 2024. The results of the literature review synthesis are grouped into six main topics. **Figure 2** visualizes the grouping of research topics.

Figure 2.
Research topic clusters



humans as the priority actor, integrated within a socio-technical framework, incorporating cognitive-perceptual factors that interact with infrastructure and regulations to create a sustainable system.

Modeling and simulation, at the second level, accounted for 24.35%. Modeling serves as a mediator for understanding the role of waste management parameters in simulating interventions involving social behavior and environmental policies without direct community intervention. Modeling and simulation provide a concrete picture for assessing the relationship between micro-behavior and macro-impacts, thus serving as a means of validating the model concept.

Another cluster, at 16.66%, represents cross-disciplinary scientific collaborations that address social behavior and the circular economy, contributing to the understanding and development of conceptual innovations on environmental issues. Collaboration between pro-environmental clusters, simulation modeling, and local contextual roles contribute to environmental protection. A combination of technology-based approaches and predictive simulation can optimize system sustainability.

An operational management system supports waste management from its source in the community to the performance of the processing system. Waste management plays a role in monitoring the general waste management system, waste volume, processed waste, technology effectiveness, and waste transportation. Operational performance requires the integration of social factors from the community, government, and industry in upstream waste management. Well-managed waste management has a significant impact on environmental protection and health.

The use of technology and energy in waste management is one systematic innovation to reduce the impact of environmental pollution. However, if technology adoption is not balanced with increased organizational capacity and readiness or user behavior, it will not produce optimal results. Aligning the operational transition of technology in waste management requires synergy from the human resources sector, government, and industry in its management.

Household waste management regulations serve as guidelines for implementing governance and economic incentives to shape energy transitions and waste management practices. Designing compatible and relevant policies to address innovative technical solutions and their implementation is a key focus. Implementing these policies within the developed conceptual model allows for analysis of their impact on overall system dynamics.

2.2. Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) is used to assess the importance of identified factors influencing household waste management from a systematic literature review. The AHP method is an alternative for making complex decisions in a hierarchy of components and evaluating them through pairwise comparisons [48]. The process (AHP) in household waste management is the initial stage of forming a hierarchical structure, which includes the main objectives, assessment criteria, and alternative household waste management systems. Hierarchical structure is essential in breaking down complex problems into more manageable components [49].

Expert selection was conducted using purposive sampling within a quadruple-helix framework to achieve a balanced representation of scientific, regulatory, operational, and social perspectives across four stakeholder entities: academia, government, industry, and the community. The experts involved included one academic in waste management, one local government official in waste policy management, one industry practitioner in waste management, one representative from a community-based waste management group, and one practitioner from an environmental institution.

The experts were selected using a purposive method, with the sample aiming to meet the following inclusive criteria: (i) professional certification and five to ten years of research and publication experience in the field of waste management; (ii) a role in policy formulation, community empowerment, and program implementation; and (iii) managerial competence within a stakeholder organization. According to international AHP standard practice guidelines, the involvement of between three and seven experts is considered adequate for multi-criteria analysis of medium complexity, and heterogeneous expert backgrounds increase robustness and reduce sectoral bias [50]. The assessment standard uses the Saaty scale (1-9) to measure the relative importance between criteria and preferences among alternatives for each criterion [51].

In order to reduce sectoral bias, each group was represented by one expert, and the aggregated assessment used geometric mean, based on literature recommendations, AHP incorporates multi-expert preferences. Pairwise criteria for constructing the comparison matrix and the consistency of expert assessments were evaluated using the Consistency Ratio (CR) < 0.10, indicating an acceptable level of consistency, validity, and reliability [52].

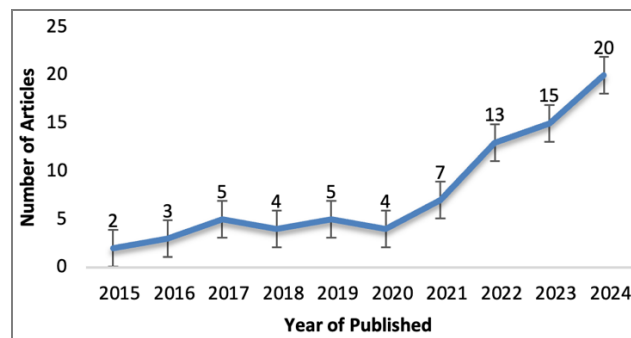
3. Results and Discussion

3.1. Approach Systematic Literature Review

The results of the literature review indicate that current research trends in household waste management predominantly focus on four key aspects: pro-environmental behavior, government policy, technological innovation, and modeling and simulation approaches. A significant body of literature emphasizes the importance of behavioral change and policy support, which are further reinforced by the integration of technologies such as the Internet of Things (IoT) and Geographic Information Systems (GIS). Modeling approaches such as Agent-Based Modeling, dynamic system simulation, and other quantitative methods are used to design efficient and adaptive data-driven solutions. These findings suggest that integrating behavior, policy, technology, and simulation is essential to building a sustainable household waste management system, especially in developing

countries. Furthermore, the application of modeling and simulation integrated with technology in waste collection processes has demonstrated potential to reduce operational costs and carbon emissions significantly [53], [54]. The distribution of the 78 reviewed articles based on can be grouped based on the number of articles **Figure 3**.

Figure 3.
Number of published
papers annually



The growth pattern of household solid waste research can be interpreted as a response to increasing environmental pressures and the growing need for more effective waste management solutions. The increase in publications from 2022 to 2024 can provide an overview of the accumulation of research conducted, particularly after the pandemic, where environmental and sustainability issues have become more crucial on the global agenda. The graph depicting this trend will show a sharp upward curve, especially from 2021 to 2024.

Figure 3 illustrates the increasing trend in waste management research in general. Furthermore, research dominated by municipal waste management demonstrates the consistency of research as a foundation for a structured approach to understanding system complexity. Municipal waste management research focuses on service structure patterns, material flows, infrastructure capacity, the circular economy, and macro performance indicators. Research integration bridges collaboration between infrastructure, processing technology, and user behavior as a framework for modeling social, technical, and policy interactions.

Behavior and social dimensions are human-based research approaches with a focus on the interaction between environmental ecosystems, social norms, 3R literacy (Reduce, Reuse, Recycle) and daily community practices. This cluster forms the basis for micro-change in society by modeling the behavior of agents who play a priority role in influencing system performance. Behavior and social dimensions are the second priority, emerging as research topics every year. The role of technology and modeling is the third priority research topic with the increasing use of simulation media in the form of agent-based modeling, dynamic systems, and digital tools for intervention

analysis in generating decisions. The simulation and modeling approach as a support for technical domain decisions in the integration of exploration of micro-behavioral changes and policies in the household waste management system.

Food waste and the environment have emerged significantly as food waste becomes a global issue and critical environmental sustainability is at stake. Research on waste volume measurement has shifted from consumption practices, household decision-making, and behavior-based interventions in communities. The approach emphasizes sociotechnical aspects and reinforces the urgency of transitioning to a more adaptive and preventative waste management system. The literature review presents the movement of technical-sectoral research to sociotechnical research by combining dynamic modeling and simulation approaches. Modeling prioritizes an agent-based modeling framework in exploring the relationships between household agents, processing system capacity, technology use, and policy interventions. The research direction suggests intertopic collaboration into a simulation-based predictive model that can complement the limitations of the sectoral approach in household waste management studies.

3.2. Research Methods

The four existing methods are based on the literature on the scope of household waste management research. First, 34.63% of the studies employed experimental methods. Experimental methods focus on evaluating perceptions of policy implementation, assessing behavioral interventions, and predicting the amount of waste based on dynamic variables. Experimental research patterns with model-based simulations are used to test hypotheses based on data on household waste sorting, transportation, and management. Figure 4 is a clustering of research methods.

Experimental research uses empirical data, field observations, and social conditions for modeling simulation approaches, and building models to obtain accurate patterns through iterations of data testing. Validation of the model by involving active communities to study the influence of interventions and the effectiveness of household waste management. In qualitative research, as much as 25.64 % is attributed to social, cultural, and behavioral conditions of the community. Data processing sources are directly related to social phenomena, attitudes and culture, community socio-economics, and social perception factors that mutually influence policies in waste management behavior. The process of identifying measurement variables is an important part of designing relevant and valid experimental interventions. Qualitative measurements are

used to see the symptoms that occur during policy implementation and changes in community social behavior. Effective household solid waste management often requires a "mixed methods" approach with qualitative, quantitative, and experimental data collected and analyzed simultaneously or sequentially to mutually reinforce findings and provide a richer perspective.

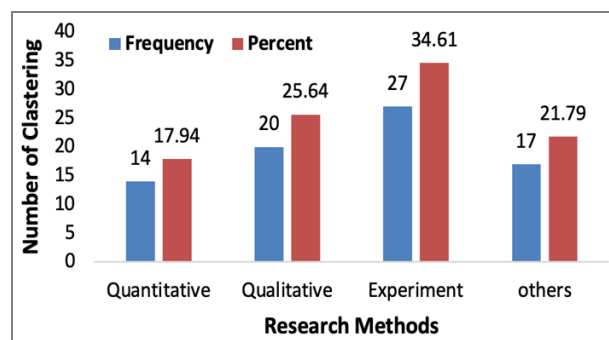


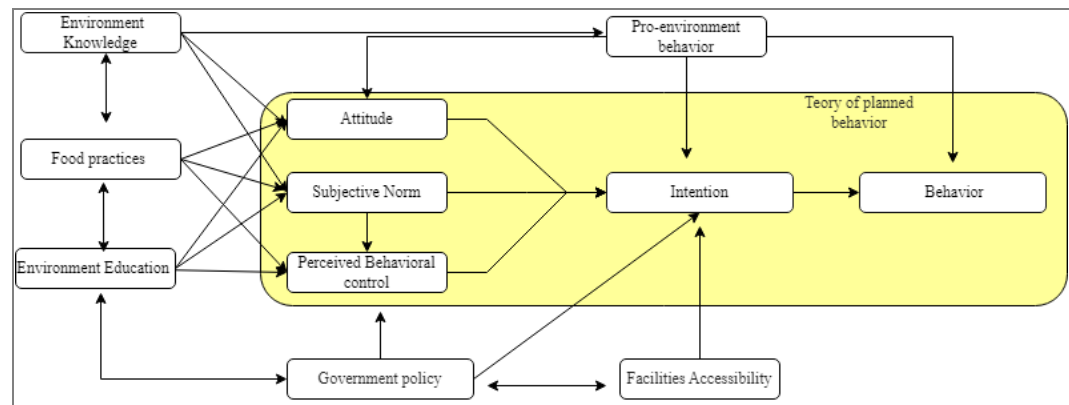
Figure 4.
Clustering of research
methods

3.3. Household Waste Model

Social and multidisciplinary scientific approaches are a part of decision analysis in exploring psychological and cultural factors in supporting sustainable household waste management. Developing collaborative and system-based models, involving communities, academics, technology, and government institutions. Furthermore, agent-based modeling or dynamic system approaches can be used to map interactions between actors and evaluate long-term impacts through intervention models. Approaches such as Agent-Based Modeling (ABM) and System Dynamics are used to simulate the interactions between actors and the dynamics of household waste, analyze the impact of policies on waste sorting, and disposal behavior. Modeling and simulation of household waste management are priority sectors to be developed [55] with the concept of the theory of planned behavior (TPB) as the basis for development in producing relevant and valid models [56]. Model development with socio-demographic factors, individual behavior, and stakeholder contributions [26] by considering aspects of environmental sustainability [57] the role of technology and sustainable waste management [58], [59]. The results of the literature

review analysis were used to identify key variables in preventing the household waste production cycle. The identified variables will be combined with the Theory of Planned Behavior to create a new model. **Figure 5** shows the new household waste model.

Figure 5.
Household waste
model



Previous research on household waste management has consistently emphasized the significance of parameters such as environmental knowledge, policy support, access to waste management facilities, and pro-environmental orientation. Building upon this foundation, the present study developed an initial model of household waste management by integrating variables and relational levels drawn from prior studies [10], [60], [61], [62], [63]. The model was constructed through an extensive literature review, identifying 11 key variables, which were subsequently evaluated using the Analytical Hierarchy Process (AHP) to determine their relative importance.

Food practices are a multidimensional behavioral construct that represents the actualization of the food consumption cycle, encompassing decisions about initial planning, purchasing, storage, cooking, meal preparation, and food waste management [64]. Empirically, food practices indicators represent primary household decision points that directly contribute to household food waste. The food practices construct, as a downstream behavioral construct, differs conceptually from the upstream psychological drivers of the Theory of Planned Behavior (TPB). Food practices are positioned as a bridging variable from intention to actual behavior, so strengthening one component alone will not result in significant behavioral change.

The Theory of Planned Behavior (TPB) encompasses upstream psychological determinants (attitude, subjective norm, perceived behavioral control, and intention) that can explain an individual's motivation and readiness to act [65]. However, food practices provide a snapshot of the actual household actions in adopting and implementing behaviors. The six food practices indicators constitute a latent construct because they represent interrelated and repetitive cycles and are not stand-alone psychological determinants [36]. The explicit separation between TPB and food practices provides a clear distinction between cognitive-perceptual factors and concrete operational practices, thus maintaining discriminant validity between constructs [66]. This approach maintains model parsimony by avoiding conceptual redundancy, as the attitudinal and behavioral control dimensions are already covered in TPB, while food practices focus on the actual implementation of household activities [67]. Food waste is the result of the interaction between psychological determinants and the household food practice system, but is not simply a consequence of individual intentions [68].

A conceptual model for household waste management will be developed through a series of statistical and predictive tests to determine its reliability in describing real-world conditions. The conceptual model is built using a micro-behavioral survey of households with a sample size of 200 to 500, followed by interventions based on Theory of Planned Behavior (TPB) variables and interacting agents. Parameters from the household survey serve as input for Agent-based modeling (ABM) to visualize actor heterogeneity, social interactions, and the resulting behavioral impacts.

Model calibration is performed using household survey data and validated through modeling and simulations with empirical observations [69]. Agent-Based Modeling serves as a policy experimentation platform for evaluating intervention scenario schemes [6]. Model validation is conducted using a pattern-oriented modeling approach, examining simulation results for food waste levels, waste sorting, and food practice adoption, as well as empirical data distribution to assess the model's structural and behavioral suitability. The performance of the predictive model concept is evaluated using out-of-sample comparisons and scenario-based accuracy matrices. Research studies are planned in urban areas to test several intervention scenarios. Agent-based

modeling is an experimental platform for assessing interventions at the individual level, which then translates into collective behavior change. Model concepts are evaluated based on scenario analysis results, stakeholder feedback, and comparisons of effectiveness between interventions, supporting evidence-based policy design.

While previous models have primarily focused on the relationship between community awareness and the effectiveness of waste management systems, they have largely overlooked a critical dimension: food practices. The inclusion of food practices addresses a significant gap by capturing behaviors that directly contribute to household waste generation. This variable is essential for deepening our understanding of the factors that shape community perceptions and behaviors toward sustainable waste management.

3.4. Analytical Hierarchy Process

The AHP model consists of four main steps, namely: first, defining the problem; second, compiling a decision hierarchy according to the objectives; third, creating a pairwise comparison matrix; and fourth, comparing priorities to obtain alternative priorities. The analytical hierarchy process (AHP) is one of the most popular and widely used multi-criteria evaluation tools used to determine the relative weights of the importance of each criterion based on the pairwise comparison. Assessment in decision making uses pairwise comparisons to determine the relative importance of variables to be validated through the consistency ratio. The results of the five experts' responses on the main criteria, aggregated using the geometric mean, are presented in **Table 1** which includes the comparison matrix and the main criteria vector.

Table 1.
Pairwise comparison
matrix

Criteria	EE	KE	PEB	ATT	PBC	SN	FA	GP	INT	BE	FP
EE	0.0451	0.0341	0.0562	0.0191	0.0698	0.0444	0.0895	0.0982	0.0811	0.0254	0.0200
KE	0.0451	0.0341	0.0449	0.0191	0.0233	0.0222	0.0448	0.0393	0.0811	0.0154	0.0400
PEB	0.1805	0.1705	0.2247	0.1366	0.1860	0.1556	0.4476	0.1965	0.1351	0.3843	0.2797
ATT	0.3159	0.2387	0.2247	0.1366	0.1628	0.1111	0.0895	0.0982	0.1351	0.0769	0.0799
PBC	0.0149	0.0341	0.0270	0.0191	0.0233	0.0444	0.0125	0.0275	0.0541	0.0108	0.0400
SN	0.0226	0.0341	0.0315	0.0273	0.0116	0.0222	0.0125	0.0275	0.0270	0.0108	0.0080
FA	0.0451	0.0682	0.0449	0.1366	0.1628	0.1556	0.0895	0.1965	0.1892	0.0769	0.1598
GP	0.0903	0.1705	0.2247	0.2732	0.1628	0.1556	0.0895	0.1965	0.1892	0.2306	0.2796
INT	0.0149	0.0113	0.0449	0.0273	0.0116	0.0222	0.0125	0.0275	0.0270	0.0154	0.0130
BE	0.1354	0.1705	0.0449	0.1366	0.1628	0.1556	0.0895	0.0648	0.1351	0.0769	0.0400
FP	0.0903	0.0341	0.0315	0.0683	0.0233	0.1111	0.0224	0.0275	0.0811	0.0769	0.0400
$\lambda_{max} = 11.474$, $CI = 0.04743$, $RI = 1.51$, $CR = 0.0314 < 0.1$ YES											

Note: EE=Education Environment; KE = Knowledge Environment; PEB = Pro-environmental Behavior; ATT = Attitude; PBC = Perceived Behavior Control; SN = Subjective norm; FA = Facilities Accessibility; GP = Government policy; INT = Intention; BEV = Behavior; FP = Food Practices

Table 1 represents the first stage, where 11 criteria are compared in pairs, and the pairwise comparison matrix has undergone normalization. The resulting consistency ratio indicates a recommended area ($CR = 0.0314 < 0.10$), in accordance with the Analytic Hierarchy Process [52]. Next, to minimize subjective bias and increase the robustness of the results, a systematic step-by-step process was implemented. First, a panel of experts from different institutions (academics, government, industry, and community) was convened to obtain diverse perspectives for decision-making assessments [70]. The experts were briefed on the scope and technical aspects of the research, including the operational definition of each variable, and then conducted in-depth interviews. Second, all experts provided independent assessments. The expert assessment results were combined in a pairwise comparison matrix aggregated using the geometric mean to reduce individual subjectivity and produce more stable variable weights [71].

Third, sensitivity testing was conducted to ensure consistency in the ranking results for each variable. The goal was to identify how small, fluctuating changes could significantly alter the ranking of alternative criteria. The simulation process for variations in the weighting of the main criteria uses a parameter of $\pm 10\%$ [50]. The results of the simulation of changes in priority weights for pro-environmental behavior show stable value weights, thus indicating that the conceptual model is stable against small fluctuations. This approach can confirm the model concept in evaluating the robustness of the ranking and ensure that decisions are not dependent on the results of dominant assumptions. **Table 2** the results of the expert judgment.

The assessment results indicate that the household waste model prioritizes the pro-environmental behavior variable, which holds a significance value of (23.8%). This variable emerges

Table 2.
Priority weight ranking

No	Variable	Priority (%)	Rank
1	Education Environment	0.0507	7
2	Knowledge Environment	0.0350	8
3	Pro-environmental behavior	0.2132	1
4	Attitude	0.1419	3
5	Perceived Behavior Control	0.0263	9
6	Subjective Norm	0.0203	10
7	Facilities Accessibility	0.1147	4
8	Government policy	0.1767	2
9	Intention	0.0196	11
10	Behavior	0.0945	5
11	Food Practices	0.0517	6

Facility accessibility ranks fourth with a contribution of 14.8%, acting as a supporting factor in providing infrastructure and access for effective household waste management. Behavior occupies the five position (9.45%), supporting the idea that behavioral change is both an objective and a dependent construct in the waste management model. The variables food practices (5.17%) and educational environment (5.07%) showed moderate contributions, indicating their supportive but not dominant role in the model. In contrast, variables such as environmental knowledge (3.50%), perceived behavioral control (2.63%), subjective norms (2.03%), and intention (1.96%) had lower weights. Lower-ranked variables exert indirect effects, depending on the presence and interaction of higher-priority factors.

3.5. Discussion

The results of the household waste model priority weight ranking provide important insights into the variables influencing sustainable practices. The first-ranked variable was pro-environmental behavior (21.32%), emphasizing that reducing, reusing, and recycling behavior is a fundamental component of environmental interventions. Pro-environmental behavior provides an alternative for reducing household waste by prioritizing consistent and responsible environmentally based management. The results of the model assessment showed consistency with research by Binxian Gu *et al.* [72] and Hidalgo Crespo [63], which showed that environmental and social parameters were priorities in household solid waste management.

The second priority, government policy (17.67%), emphasizes the role of institutions in the formation and implementation of regulations, as well as their monitoring. The contribution of government institutions through policy frameworks, facilitating and adopting concrete actions, imposing sanctions, and planning infrastructure investments. Government policy not only provides guidelines but can also create a supportive environment and motivation for responsible waste management. The findings regarding government policy align with research [73], which emphasizes policy implementation and management monitoring. Attitude (14.19%), ranked third, reflects the internal cognitive and emotional predisposition of individuals toward environmental issues. This supports the notion that sustainable behavior is rooted not only in knowledge but also in belief systems and value alignment. Therefore, interventions should incorporate educational campaigns and social marketing strategies that aim to influence attitudes toward environmental responsibility.

The fourth-ranked variable, facility accessibility (11.47%), demonstrates the importance of physical infrastructure and information systems in encouraging environmentally friendly behavior. Limited access to waste sorting facilities and recycling centers can hinder waste collection systems. Therefore, improvements in physical infrastructure must be accompanied by behavioral and policy interventions. Observed behavior (9.45%), placed fifth, functions as both an outcome and a reinforcing feedback loop within the model. This activity demonstrates the extent to which the variables are applied in real-world practice. Furthermore, food practices (5.17%) and educational environment (5.07%) contribute significantly, indicating that daily habits and activities in producing waste can play a role in forming the basis for behavioral change. Low-ranking variables such as environmental knowledge, perceived behavioral control, subjective norms, and intentions indicate a gap between awareness, intention, and action. Although these factors are often implemented in behavioral models, they indicate a lack of application of knowledge to actual practice.

Overall, the household waste model emphasizes that achieving environmental sustainability at the household level requires an integrated approach. Pro-environmental behavior change, supportive policies, positive attitudes, and ease of facility accessibility access are the foundations of integrated waste management [74]. Future strategies should consider multilevel interventions

as a key indicator influencing household waste reduction within the framework of environmental sustainability. The second priority is (18.7%), with the government policy variable as the main framework and guidance for national waste management. The third priority is individual attitude (14.19%), highlighting the need for clear guidelines in the form of regulations or policies to shape appropriate behavior.

that combine individual, community, and institutional efforts to ensure long-term sustainability outcomes.

4. Conclusion

Household waste management remains a global challenge, underscoring the crucial role of regulatory frameworks as a foundation for governance and public awareness. This study emphasizes the need for collaboration to increase waste reduction at the household level. Despite increasing awareness of waste management, challenges remain in curbing household waste generation. To address this issue, the study identifies and evaluates eleven key criteria using the Analytic Hierarchy Process (AHP), a structured decision-making method supported by expert judgment. The results highlight pro-environmental behavior, government policy, and individual attitudes as the top-ranked variables influencing the sustainability of household waste management systems. Furthermore, food practices and educational environment are identified as significant behavioral factors directly contributing to waste formation. These findings call for the development of targeted mitigation models that prioritize behavioral and institutional interventions. These findings call for the development of targeted mitigation models that prioritize behavioral and institutional interventions. Future research should focus on identifying measurable indicators for each criterion and assessing the model's effectiveness in real-world settings. Moreover, integrating digital technologies such as the Internet of Things (IoT) and Geographic Information Systems (GIS) into waste collection, sorting, and processing can enhance operational efficiency through real-time monitoring. Achieving success in household waste management ultimately requires a multi-sectoral approach involving government, communities, private actors, and industry to establish comprehensive and sustainable governance mechanisms.

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Authors' Declaration

Authors' contributions and responsibilities – Aswan Munang: Writing - original draft, Visualization, Software, Resources, Methodology, Investigation, Data curation, Conceptualization. Hari Purnomo: Validation, Methodology, Formal analysis, Conceptualization. Winda Nur Cahyo and Imam Djati Widodo: Review and editing, Validation, Supervision, Formal analysis.

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