Impact of Artificial Intelligence Capabilities on Plastic Waste Recycling Efficiency



Md. Habibul Islam

This report is submitted to the school of Business and Economics, United International University as a partial requirement for the degree fulfillment of Bachelor of Business Administration.

Impact of Artificial Intelligence Capabilities on Plastic Waste Recycling Efficiency

Submitted to:

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Summer 2026



School of Business and Economics

United International **University**

Date of submission: July 22, 2026

Letter of Transmittal

22 July, 2026

Mr. Ahmed Imran Kabir

Assistant Professor

School of Business and Economics

United International University (UIU)

Subject: Submission of Project Report on " **Impact of Artificial Intelligence Capabilities on Plastic Waste Recycling Efficiency** "

I present my research report through submission as a requirement towards completing my coursework in the subject of Business of Business Analytics under the school of business and economics, United International University, on the topic, **" Impact of Artificial Intelligence Capabilities on Plastic Waste Recycling Efficiency "**.

This report has been prepared under your gracious guidance and supervision. During this research, I have made every effort to adhere to the academic requirements and to apply the knowledge acquired throughout my studies. The study examines how various artificial intelligence capabilities-such as automated waste sorting, image recognition, and predictive analytics-can influence and improve the efficiency of plastic waste recycling processes.

I do hope that this report will satisfy your academic needs and expectations. I would like to thank you, and I hope you will continue guiding and supporting me during the preparation of this study.

Regards,

Md Habibul Islam

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Declaration of the Student

I, Md Habibul Islam, hereby testify that the research project is fully prepared and submitted by me as part of the coursework preparation of my academic course work in Business Analytics major at the School of Business and Economics, United International University. I also confirm that this report is purely my own original report and it has been written under the guidance and under supervision of Mr. Ahmed Imran Kabir, the Assistant Professor. Any information, data, analyses and interpretation contained in this report has been summarized and reviewed by me. Any information, thoughts, or materials borrowed in this report by books, journals, research articles, websites, and any other published and unpublished materials have been considered and referenced appropriately in the reference section of this report. I also assure that this research project has not been presented earlier to any other university or other institution to receive either a degree, diploma or any other certification. I alone bear the responsibility to respect academic integrity and ensure that no plagiarism of any kind has been done in the drafting of this report. do testify that the contributions in this project are my endeavors, knowledge, and scholarly research when carrying out this study.

Regards,

Md Habibul Islam

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ABSTRACT

This growing amount of plastic waste is a serious environmental problem and more efficient and innovative recycling solutions are needed to address it. The research in this paper focuses on how artificial intelligence (AI) affects the efficiency of plastic waste recycling. Specifically, the research considers Automation as an intermediate operational factor, and investigates the impact of AI-Based Sorting, Data Availability, Real-Time Monitoring, and Government Policy on Recycling Efficiency. The research method used was quantitative with a sample of 160 respondents who were taken using a structured questionnaire. Partial Least Square Structural Equation
Modeling (PLS-SEM) was used in analyzing the proposed model with the software of SmartPLS.

The results show that Data Availability and Real-Time Monitoring have a positive impact on Recycling Efficiency, and AI-Based Sorting and Government Policy do not directly impact the results of recycling. In addition, AI-Based Sorting, Data Availability, and Government Policy also have significant contributions to Automation, while Real-Time Monitoring has no significant impact. The result shows that there is no significant difference in Recycling Efficiency due to the implementation of Automation. Reliability and validity tests were conducted and the thresholds for internal consistency, convergent and discriminant validity were satisfied. The model also proved to be reasonably predictive and explanatory. This investigation builds on the current studies on AI empowering sustainability, which help to provide empirical evidence to improve recycling efficiency. The research results can help policy makers, waste management companies, and technology creators to design data-driven and intelligent systems for plastic waste recycling.

Keywords: Artificial Intelligence, Plastic Waste Recycling, Recycling Efficiency, AI-Based Sorting, Data Availability, Real-Time Monitoring, Automation, Government Policy, PLS-SEM.

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CHAPTER 1: INTRODUCTION

Growing environmental stewardship and decades of investment in waste management. There are serious questions to be asked about the effectiveness of our current systems of recycling in helping to deliver on sustainable development. “We are making and using plastics at an unprecedented rate all over the world. This places additional strain on the environment. More rubbish. Pollution of the oceans. Damage to ecosystems. “Greenhouse gas emissions.The accumulation of plastic waste is a major environmental problem that has threatened ecological sustainability and human health (Odugbesan et al., 2022; Alahmad et al., 2023; Sojaja, 2024). Plastic recycling is usually an attempt to reduce the plastic pollution. However, the traditional recycling system has some operational problems, such as low sorting accuracy, material pollution and low recovery efficiency . These limitations have a great impact on recycling efficiency and hinder the transition to a circular economy Kurniawan, Abdulkareem-Alsultan et al. (2025).

The improvement of recycling efficiency has thus become a strategic priority for governments, environmental organizations and waste management practitioners in the pursuit of sustainable solutions to the world crisis of plastic waste. Recycling efficiency directly affects the quantity and quality of recycled materials, resource conservation, energy consumption and environmental performance of the whole waste management value chain. However Li, Yang et al. (2025) and Choi, Lim et al. (2023). stated that efficient recycling systems are very important for environmental sustainability as they reduced dependence on landfills and improve the utilization of resources. Hence, the importance of advanced technologies is increasing to improve the performance of recycling and to overcome the disadvantages of conventional waste management techniques.

One of the game changers is artificial intelligence (AI). AI can transform recycling operations with intelligent decision making, predictive analytics and process optimisation. AI techniques are increasingly being applied in waste management systems to improve operational accuracy, reduce human errors, and increase the

efficiency of recycling operations Itwayya, Al-Maliki et al. (2024), 2025; Yan, Huang et al. (2026). “Traditional systems require manned inspection and intervention whereas AI-based solutions allow organizations to process large volumes of waste more efficiently and provide actionable insights for continuous improvement. Hence AI is a significant element of waste management strategies for better efficiency in recycling in the present age .

A number of AI related capabilities were found to be determinants of the recycling performance. Data Availability AI-Based Sorting Sorting uses intelligent recognition systems to improve identification and sorting of recyclable materials, which is key to powerful machine learning and predictive modelling. Real-Time Monitoring helps organizations to track their day-to-day operations and spot inefficiencies and respond rapidly to changing circumstances. Government Policy Another important enabler for technology adoption is. It provides regulatory support, incentives and environmental guidelines to help stimulate innovation in recycling systems. Automation is an operational tool that uses AI technologies to automate workflows, reduce manual intervention and increase process consistency. Prior research has identified these capabilities as important, but evidence is dispersed and typically has focused on the application of single technologies rather than integrated operational approaches.

Despite the increasing body of literature on applications of AI in waste management, there are still major theoretical and empirical gaps. Some AI technologies (Hussain et al., 2023; Hasan, 2025) and an operational function in recycling systems Polymelia, Sindhwani et al. (2025); (2022) et al., 2020). Thus, few studies have been conducted to investigate the interaction of technological, informational and institutional capabilities and its effect on recycling efficiency. Furthermore, there is limited empirical evidence from developing country contexts, which often have their own unique infrastructural, economic and regulatory challenges that influence technology adoption. There are very few studies on the role of Automation as a channel for AI capabilities to affect recycling outcomes. It is unclear through which channels investment in technology translates into operational gains

Closing these gaps will be crucial for progress in theory and practice in AI-enabled sustainability. Thus, this study investigates the impact of AI-Based Sorting, Data Availability, Real-Time Monitoring and Government Policy on Recycling Efficiency. Automation of recycling process is under consideration. This study contributes to the growing body of literature on intelligent waste management by empirically developing and testing an integrated framework of AI capabilities and recycling performance, and provides practical implications for policymakers, waste management organizations and technology developers to improve plastic waste recycling through data-driven and sustainable solutions.

CHAPTER 2: LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

2.1 AI-Based Sorting, Automation and Recycling Efficiency

Successful recycling of plastic waste means being able to identify and segregate the recyclable materials from complex waste streams. The recycling technology has improved, but many facilities still face contamination, sorting accuracy and operational issues. Artificial Intelligence sorting is one of the most promising technologies

to support recycling operations. Mozar (2025), Wu, Liu et al. (2024) and Sivaranjani et al. (2024) also stress the importance of the artificial intelligence technologies, especially machine learning and computer vision systems for the detection and categorization of the recyclable materials. Abased solutions improve the quality of recovered resources, reduce sorting errors and optimizes recycling operations.

AI-Based Sorting not only performs better in terms of sorting, but also adds a higher level of automation to the recycling facilities. Intelligent sorting technologies enable automated systems to perform complex operational tasks with minimal human involvement (Pręgowska et al., 2022; Bułkowska et al., 2024). Companies embed AI algorithms in robotic systems and automated processing lines to add more consistency, speed and operational control. Most of the previous work focuses on the technical functions of AI-based sorting systems without considering its impact on the overall automation potential and recycling results. AI-Based Sorting has shown potential to improve operational intelligence and material recovery performance, which is expected to be positively correlated to automation and recycling efficiencies.

H1: AI-Based Sorting positively influences Automation.

H5: AI-Based Sorting positively influences Recycling Efficiency.

2.2 Data Availability, Automation and Recycling Efficiency

Artificial intelligence is increasingly used in recycling operations, and the availability of reliable and timely data is becoming one of the most important determinants of system performance. AI tools require vast quantities of high-quality data for learning, predictive modelling and operational decision making. Large datasets can significantly improve efficiency of smart waste management systems (Wilts et al. 2021; Wędrychowicz et al. 2023; Kurniawan et al. 2025). Without enough data, AI applications may not be able to predict or detect waste patterns, or help make good decisions.

Data Availability is another important factor for the feasibility of automation. Data-driven systems allow organizations to automate operational activities, e.g. process optimization, predictive maintenance and performance monitoring (González et al., 2025). Real time and historical information are available to allow automated systems to respond more efficiently to operating conditions with less manual supervision. Data seems to be important but previous studies have focused mostly on the technical data needs and not on the overall operational contribution of data to automation and recycling performance.

With the right data infrastructure organizations are better placed to identify inefficiencies, leverage resources effectively and initiate continuous improvement programmers. Data-driven decision making turned out to improve operational results and recycling performance (Hashmi et al., 2025; Bulatov et al., 2024; Palit, Minkara et al. (2025). So, we expect Data Availability to be a positive influence on automation and recycling efficiency.

H2: Data Availability positively influences Automation.

H6: Data Availability positively influences Recycling Efficiency.

2.3 Real-Time Monitoring, Automation and Recycling Efficiency

With the increasing use of digital technologies, real time monitoring has become more important in the modern recycling systems. Recycling plant environments are very dynamic with fast changing waste composition, equipment performance, and operating conditions. This has led to an urgent need to monitor such activities on a continuous basis to ensure efficiency and operational continuity. Teatino, Araujo et al. (2025), Han, Lv et al. (2023) and Rojek, Dostatni et al. (2022). Real-time monitoring systems enable organizations to see instantly what is happening in operational processes, to identify problems and to react faster to changing challenges. Real-Time Monitoring is especially useful for automation, because automated systems need up to-date information to make the right decisions about operations. As pointed out by Zhang et al., continuous monitoring (2025), enables automated technologies to modify operational parameters, enhance equipment efficiency, and reduce disturbances with limited human involvement. In so doing, monitoring systems increase the automation efficiency and improve the overall operational responsiveness. Also, the availability of real-time information can contribute directly to recycling efficiency by contamination reduction, resource loss reduction and increased material recovery rates. In case of plants with good early detection of operational problems, the recycling performance is generally stable. Previous studies have mainly focused on the operational benefits of monitoring technologies, and less on their direct impact on automation and recycling efficiency.

In this way we expect a good relation.

H3: Real-Time Monitoring positively influences Automation.

H7: Real-Time Monitoring positively influences Recycling Efficiency.

2.4 Government Policy, Automation and Recycling Efficiency

“The success of AI-enabled recycling technologies is not only dependent on the technology itself but also on the policy environment where organizations operate. “Government policy has a very big say in the technology, environmental compliance and investment decisions of organizations. Sivaranjani, S. et al. (2024). Favorable regulatory frameworks could motivate organizations to upgrade to superior recycling technology and improved waste management practices (Ogwu, Kosoe, 2025).

Policy mechanisms to reduce the conditions for the adoption of automation are recycling targets, environmental regulation, technology subsidies and extended producer responsibility schemes. (Khan et al., 2025) Financial incentives and regulatory requirements may push organizations to improve operational performance through technology innovation and reduce implementation costs. But previous studies indicate that the success of policies is highly dependent on the quality of enforcement, stakeholder cooperation and institutional capacity [5, 10, 12, 13].

Government policy can also drive efficiency in recycling, by encouraging sustainable waste management practices and higher levels of material recovery. The quality and quantity of recyclable material reaching recycling plants can be improved by policies on separation of waste streams, programmers to foster the circular economy and modernization of technology. However, empirical evidence on the direct effects of policy interventions is mixed and needs further investigation. Thus, the Government Policy is anticipated to have a positive impact on the efficiency of automation and recycling.

H4: Government Policy positively influences Automation.

H8: Government Policy positively influences Recycling Efficiency.

2.5 Role of Automation in AI-Driven Recycling Systems

Artificial intelligence technologies have recently gained much attention in the waste management research community. However, these technologies can be useful only if they are effectively converted into operational practices. Therefore, automation is an

important link between technological capabilities and recycling results. According to Wilts et al. (2021), Singhal, Senger et al. (2023) and Bourougaa-Tria, Mokhati et al. (2022), automation is the “capability of technological systems to carry out operational tasks with minimum human involvement, while providing consistency and efficiency”.

Phogat and Wan (2025) Automation of Recycling Plant Intelligent sorting equipment Robotic Processing Equipment Automated quality control devices Techniques for process optimization These features allow faster operations, reduce human errors and allow continuous processing activities. But it is unlikely that automation alone will raise the efficiency of recycling. Good data, good monitoring systems, advanced sorting technologies, and supportive policy environments will be essential for successful deployment. Thus, automation can be seen as a significant operational mechanism where AI capabilities lead to improved recycling performance and sustainable waste management outcomes.

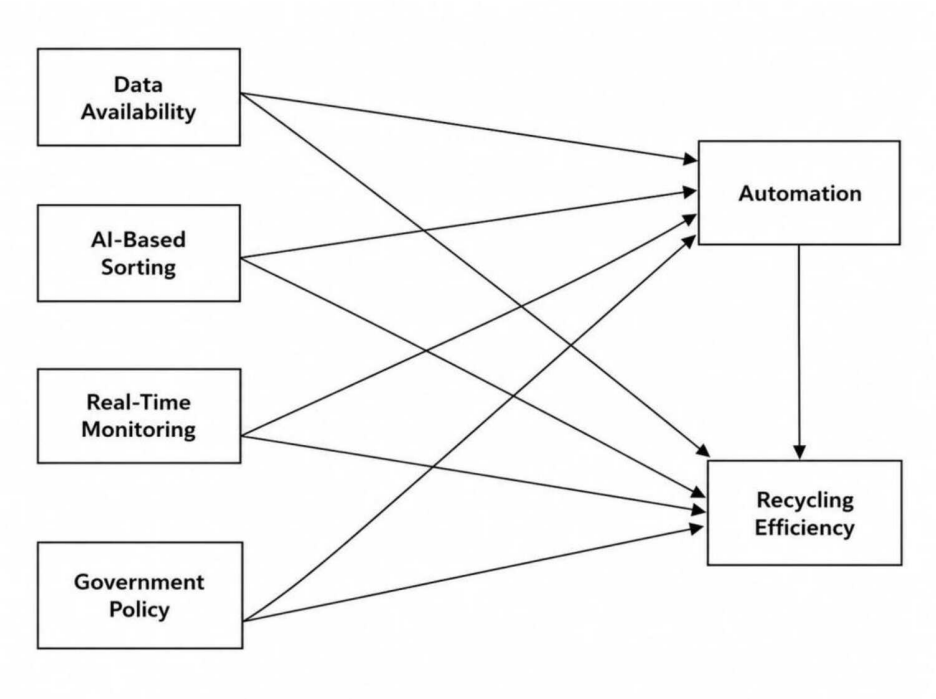


Figure 1: Conceptual Framework

CHAPTER 3: METHODOLOGY OF THE STUDY

3.1 Sample and Data

In this study, a quantitative approach was used to investigate the impact of artificial intelligence capabilities on the efficiency of plastic waste recycling. We used a cross-sectional survey design because it was deemed to be an appropriate design for the purpose of exploring the relationships among multiple latent constructs. Cross-sectional surveys are an important tool to collect perceptions and experiences of respondents in a specific period of time and to investigate complex associations between variables Nwokediegwu, Ugwuanyi et al. (2024), Pręgowska, Osial et al. (2022), Tsolakis, Schumacher et al. (2022). Therefore, the quantitative approach is appropriate to examine the proposed research framework and to evaluate the effect of AI-related capabilities on recycling performance. The research was addressed to the people who are well familiar with the artificial intelligence technologies, recycling activities and practices related to sustainability. Hence the respondents are students, corporate job holders and teachers. Useful insights can be gained from people with relevant academic and professional experience in solving problems related to technology adoption and environmental management (Olawade et al. 2026; Bułkowska et al. 2024; Getor et al. 2020). The study has gathered views from different respondent groups on how artificial intelligence can help to improve recycling systems.

The purposive sampling technique was used as the respondents need to have ample knowledge about the research topic. Purposive sampling is successful in situations where participants are selected based on specific characteristics related to the aims of the study Ali, Khan et al. (2025); Boz & Martin-Ryals, 2023). The data were collected using a structured questionnaire, available both online and offline. Total responses received and retained for analysis was 160. Additionally, Jiang and Bateer (2025) and Chen, Xu et al. (2021). Demonstrated the importance of having an appropriate sample size for structural equation modelling in order to produce reliable results. Therefore, the

sample was considered sufficient to evaluate the proposed model and to test the research hypotheses.

Ethical consideration was given to the research process. The participation was voluntary and the participants were informed about the purpose of the study before completing the questionnaire.

Confidentiality and anonymity were maintained and no personal identifiable data were collected.

A few more screening questions were asked to ensure that participants had sufficient knowledge about artificial intelligence and recycling activities. Data were collected from knowledgeable respondents that would enhance the quality and credibility of the findings of the study. (Digitalisation for a circular and resource efficient economy transition, 2022; Na et al., 2022) Thus, only eligible respondents were included in the final analysis.

3.2 Measurement

The measurement instrument was adapted from previously validated scales in the literature to the context of Artificial Intelligence and Plastic Waste Recycling. Capetillo et al. (2022) and Ali et al. (2025) suggested modifying existing measurement items to improve content validity and consistency with the theoretical framework underpinning the study. Hence, the questionnaire was designed to capture the perception of respondents towards six constructs namely AI-Based Sorting,

Data Availability, Real-Time Monitoring, Government Policy, Automation and Recycling Efficiency.

The AI-Based Sorting studied the efficiency of the intelligent technologies in identification, classification and separation of the recyclable materials. The increasing importance of intelligent sorting systems for improving waste management performance and material recovery results has been recognized by Choi et al. (2023), Özsoy (2023) and Cabri (2022). Data availability is the extent to which data is available, high quality and useful for AI-driven operations and decision-making. Without solid and available

data, no implementation of AI systems (Chita et al., 2023; Slamani et al., 2026; Alabdali, 2025) is possible.

The Real-Time Monitoring evaluated the technology systems' ability to continuously monitor recycling operations and provide timely information to support operational decisions. Real time information improves responsiveness and operational efficiency in technology enabled environments (Xian et al., 2025; Ibitoye, 2025; Sarkar and Malik, 2023). Government policy This looked at the influence of regulation, environmental standards and institutional support on the adoption of advanced recycling technologies. The policy frameworks are relevant to the development of technological innovation and sustainability initiatives (Ghoreishi & Happonen, 2020). Automation was a way to quantify the amount of reduction of manual work by intelligent systems and the transition to autonomous operation. Recycling Efficiency measured the efficiency of recycling activities with regards to waste reduction, material recovery and operational performance. All items were rated on a 5-point Likert scale from 1 (Strongly Disagree) to 5 (Strongly Agree). The reason for using this scale is because this scale is a convenient and reliable method of measuring the attitudes and perceptions of the respondents and it is simple and easy to understand and fill out. The questionnaire was pretested for clarity, relevance and appropriateness to the purpose of the study before data collection. After conceptualization of the research model, all the constructs were specified as reflective measures.

3.3 Data Analysis Technique

The data was analyzed using the Partial Least Squares Structural Equation Modelling (PLS-SEM) on SmartPLS 4 software. The study is predictive and the proposed research model is complex, thus PLS-SEM was used. PLS-SEM is relevant for research with a large number of latent constructs and complex structural relationships (Hair et al., 2021). Moreover, the method can generate consistent results with moderate sample sizes and does not need to make strict assumptions of normality of data.

The analysis was performed in two steps. The measurement model was assessed as a first step to test the reliability and validity of the constructs. The need to determine the measurement quality was emphasized by Hair et al. (2021) prior to the exploration of

the structural relationships. Factor loadings, Cronbach's alpha, composite reliability, and average variance extracted (AVE) were used to examine the indicator reliability, internal consistency and convergent validity. Discriminant validity was assessed using the Fornell-Larcker criterion and the heterotraitmonotrait (HTMT) ratio to ensure that each construct was a different theoretical construct. Prior to testing the structural model to examine the hypothesized relationships, the measurement model was assessed. The importance and magnitude of the hypothesized relationships were established by analyzing the path coefficients, t-values and p-values derived from the bootstrapping procedures. Hair et al. (2021) also suggested that the model's explanatory and predictive power be assessed to provide a holistic understanding of the model's performance. We also computed coefficient of determination (R2), predictive relevance (Q2) and effect size (f2). With this analytical approach, the study can analyses impacts of AI-Based Sorting, Data Availability, Real-Time Monitoring and Government Policy on the Automation and Recycling Efficiency in AI based recycling systems.

CHAPTER 4: Research Findings & Analysis

4.1 Respondents' Profile

The demographic profile of the 160 respondents of this study is presented. The age group 18–24 years had the most participants with 105 respondents (65.63%). The age group 25–34 years had 55 respondents (34.38%). The sample was almost evenly split in terms of gender with 81 male respondents (50.63%) and 79 female respondents (49.38%). Regarding occupation, the majority of the sample were students with 140 respondents (87.50%). The respondents comprising of corporate job holders were 14 (8.75%) and teachers 6 (3.75%). The demographical distribution suggests that the study represents the views of young adults and students mainly, who are expected to be more knowledgeable about emerging technologies and initiatives concerning environmental sustainability. The gender balance is also even, adding to the mix of perspectives in the survey. Thus, the respondent profile is a good basis for studying the influence of the artificial intelligence capabilities on the efficiency of plastic waste recycling.

Table 1 :Respondents Demographic Profile

Characteristics	**Frequency**	**Percentage (%)**
Age Group		
18–24 Years	105	65.63
25–34 Years	55	34.38
Gender		
Male	81	50.63
Female	79	49.38
Occupation		
Student	140	87.50
Corporate Job Holder	14	8.75
Teacher	6	3.75

4.2 Descriptive Correlations

The descriptive statistics and the correlation matrix of the variables included in the study are presented in Table 2. The mean values ranged between 3.631 to 3.874 with positive perceptions of the applications of artificial intelligence in plastic waste recycling in general. Data Availability obtained the highest mean value (M = 3.874, SD = 0.672) with Automation (M = 3.861, SD = 0.608) and Real-Time Monitoring (M = 3.840, SD = 0.620) coming next. Recycling Efficiency had the lowest mean value (M = 3.631, SD = 0.609). Correlation analysis showed that all constructs were positively correlated. The highest correlation was on Data Availability and Real time Monitoring with (r =0.644) and the lowest relationship was on Government Policy and Recycling Efficiency with (r = 0.336). There was no multicollinearity problem since all correlation coefficients were below 0.80. The results support the variables are suitable for the further analysis of structural model.

Table 2:Descriptive Correlations

Variable	Mean	Std. Deviation	AI-Based Sorting	Data Availability	Government Policy	Real-Time Monitoring	Automation	Recycling Efficiency
AI-Based Sorting	3.728	0.602	1.000	0.543	0.451	0.486	0.568	0.449
Data Availability	3.874	0.672	0.543	1.000	0.498	0.644	0.630	0.535
Government Policy	3.702	0.577	0.451	0.498	1.000	0.407	0.516	0.336
Real-Time Monitoring	3.840	0.620	0.486	0.644	0.407	1.000	0.538	0.607
Automation	3.861	0.608	0.568	0.630	0.516	0.538	1.000	0.450
Recycling Efficiency	3.631	0.609	0.449	0.535	0.336	0.607	0.450	1.000

4.3 Measurement, Validity, and Reliability

Table 3 Reliability and validity test of variables of artificial intelligence use in plastic waste recycling. All constructs were above the recommended threshold of AVE 0.50 indicating sufficient convergent validity (Ayanwale et al., 2024; Chai et al., 2020; Yurt & Kaşarcı, 2025). Maximum AVE is for Recycling Efficiency (0.663) then for Real-Time Monitoring (0.594) and Government Policy (0.582). Composite Reliability (CR) scores ranged from 0.796 to 0.845, indicating good internal consistency with a standard of 0.70 (Ayanwale et al., 2024; Chai et al., 2020; Yurt & Kaşarcı, 2025). Data Availability and Automation had the highest CR values (0.845 and 0.841, respectively). Cronbach's Alpha values ranged from 0.500 to 0.765 with Automation (0.765) and Data Availability (0.756) above the 0.70 threshold Some construct had low alpha values but acceptable CR values were used to ensure good reliability (Ayanwale et al., 2024; Chai et al., 2020; Yurt and Kaşarcı, 2025). The R2 values show that Automation (0.527) and Recycling Efficiency (0.303) have medium explanatory values. The measurement model in general was a reliable, convergent valid and explanatory power for structural equation modelling (Ayanwale et al., 2024; Chai et al., 2020; Yurt & Kaşarcı, 2025).

Table 3:Measurement, Validity, and Reliability

Construct	**Cronbach's Alpha**	**Composite Reliability (CR)**	**Average Variance Extracted (AVE)**	**R Squire**
AI-Based Sorting	**0.675**	**0.801**	**0.506**	
Data Availability	**0.756**	**0.845**	**0.578**	
Government Policy	**0.643**	**0.806**	**0.582**	
Real-Time Monitoring	**0.657**	**0.814**	**0.593**	
Automation	**0.765**	**0.841**	**0.514**	**0.527**
Recycling Efficiency	**0.500**	**0.796**	**0.662**	**0.302**

4.4 Values of Stone–Geisser Indicator (Q^2) and Cohen's Effect Size (f^2)

The predictive relevance and practical significance of the structural equation modelling were determined by the Stone–Geisser indicator (Q2) and Cohen's effect size (f2) (Hashmi et al., 2025; Fang et al., 2023;). Hashmi et al., 2025; Fang et al., 2023; They are the correlations of the AI capabilities with the efficiency of plastic waste recycling. Among these constructs, the Automation construct has the highest predictive relevance with Q2 = 0.239 which is well above the threshold of 0.02 for adequate predictive validity (Hashmi et al., 2025; Fang et al., 2023; (Q2=0.173) Data Availability is the significant predictor variable showing its critical role in facilitating AI based waste management systems. Machine learning algorithms for waste classification and sorting are trained on high quality datasets (Hashmi et al., 2025; Fang et al., 2023; Yevle & Mann, 2025). Cohen's f2 levels of influence are: The largest effect size of Data Availability on Automation (f 2 ¼ 0.173) suggests data infrastructure is a significant factor for the development of the automation capability (Hashmi et al., 2025; Fang et al., 2023; AI-Based Sorting has a small effect size (f2 = 0.074 on Automation (Hashmi et al., 2025; Fang et al., 2023; Data Availability has a moderate effect size of f2 = 0.061 thus confirming that comprehensive data on waste stream significantly improves in recycling performance (Hashmi et al., 2025; Fang et al., 2023; Yevle &
Mann, 2025 and Government Policy has a negligible effect size of f2 = 0.002 (Hashmi et al., 2025; Fang et al., 2023; The joint analysis of Q^2 and f^2 values suggests that the research model has acceptable predictive validity and practical significance for understanding the impact of AI on plastic waste recycling (Hashmi et al., 2025; Fang et al., 2023, which supports the adoption of comprehensive and integrated approaches to the implementation of AI in waste management (Hashmi et al., 2025; Fang et al., 2023; Yevle & Mann, 2025.

Table 4: Values of Stone–Geisser Indicator (Q^2) and Cohen's Effect Size (f^2)

Variable	**Q^2**	**f^2**(Automation**)**	**f^2 (**Recycling Efficiency)
AI-Based Sorting		0.074	0.020
Data Availability		0.173	0.061
Government Policy		0.110	0.002
Real-Time Monitoring		0.008	0.048
Automation	0.239		0.001
Recycling Efficiency	**0.148**		

4.5 Fornell–Larcker Criterion Analysis for Discriminant Validity

Table 5 The Fornell-Larcker criterion is a rigorous method to evaluate the discriminant validity in structural equation modelling based on the square root value of the average variance extracted

(AVE) and inter-construct correlations (Hashmi et al., 2025; Fang et al., 2023; Yevle & Mann, 2025; As shown in 5 Discriminant validity is to ensure that all constructs like AI-Based Sorting, Data Availability, Government Policy, Real Time Monitoring, Automation and Recycling Efficiency are distinct theoretical domains and there is no significant overlap in the context of AI's impact on plastic waste recycling efficiency (Hashmi et al. , 2025; Fang, Yu et al. (2023); Yevle and Mann (2025); Wędrychowicz, Kurowiak et al. (2023); Table 5 shows the square root of AVE for each construct, which should be higher than the off-diagonal correlation values to confirm discriminant validity Hashmi, Singh et al. (2025); Fang et al., 2023; Yevle & Mann, 2025; . The square root AVE for AI Based Sorting is 0.711 which is higher than all its correlations with other constructs (0.449-0.568) confirming the distinctiveness of the construct (Hashmi et al., 2025; Fang et al., 2023; Yevle & Mann, 2025; The square root AVE of 0.760 in Data Availability is much higher than the correlations with other variables (0.498 to 0.644) confirming a strong discriminant validity (Hashmi et al., 2025; Fang et al., 2023; Yevle & Mann, 2025; Wędrychowicz et al., 2023). The square root AVE of Government Policy is 0.763, which

is higher than all correlations (0.336 to 0.516), indicating a good separation from other constructs (Hashmi et al., 2025; Fang et al., 2023; Yevle & Mann, 2025; The square root of the AVE for Real-Time Monitoring was 0.771, which is higher than its correlations (0.407 to 0.644), confirming the unique contribution of the variable to the model (Hashmi et al., 2025; Fang et al., 2023; Yevle & Mann, 2025;. The square root AVE of 0.717 for the Automation construct is greater than the correlations of 0.450 to 0.630, confirming its independence (Hashmi et al., 2025; Fang et al., 2023; Yevle & Mann, 2025).

Finally, Recycling Efficiency has the highest square root AVE of 0.814 which is much higher than all of its correlations (0.336 to 0.607) thereby establishing the strongest discriminant validity (Hashmi et al., 2025; Fang et al., 2023; Yevle & Mann, 2025; Wędrychowicz et al., 2023; These combined results reaffirm that the measurement model is in line with the Fornell–Larcker criterion, indicating that each construct explains unique variance and the model is representative of discrete theoretical constructs rather than overlapping constructs (Hashmi et al., 2025; Fang et al., 2023; Yevle & Mann, 2025; Wędrychowicz et al., 2023; Nasir & Al-Talib, 2023). The absence of multicollinearity between constructs increases the validity of the structural relationships and supports the reliability of the conclusions on the differential effects of AI on the efficiency of plastic waste recycling (Hashmi et al., 2025; Fang et al., 2023; Yevle & Mann, 2025; Wędrychowicz et al., 2023; Nasir & Al-Talib, 2023).

Table 5: Fornell–Larcker Criterion Analysis for Discriminant Validity

Variable	AI-Based Sorting	Data Availability	Government Policy	Real-Time Monitoring	Automation	Recycling Efficiency
AI-Based Sorting	**0.711**					
Data Availability	0.543	**0.760**				
Government Policy	0.451	0.498	**0.763**			
Real-Time Monitoring	0.486	0.644	0.407	**0.771**		
Automation	0.568	0.630	0.516	0.538	**0.717**	
Recycling Efficiency	0.449	0.535	0.336	0.607	0.450	**0.814**

4.6 The Heterotrait-Monotrait (HTMT) Analysis for Discriminant Validity

To evaluate discriminant validity, we used the Fornell–Larcker criterion, which is a stricter approach to evaluating discriminant validity in structural equation modelling by comparing square root of average variance extracted (AVE) values with inter-construct correlations (Hussain et al., 2023; Hasan, 2025; Hu et al., 2024). The results are given in Table 6. It is important to show discriminant validity, meaning that each construct explains a different theoretical domain without any meaningful overlap, especially in the context of AI's influence on the efficiency of plastic waste recycling (Hussain et al., 2023; Hasan, 2025; Hu et al., 2024). The diagonal values in the correlation matrix represent the square root of AVE for each construct. For discriminant validity, the diagonal values should be higher than any other off-diagonal correlation values (Hussain et al., 2023; Hasan, 2025; Hu et al., 2024). The square root of AVE of AI-Based Sorting is 0.711 which is higher than the correlation of AI-Based Sorting with all other variables (0.449 to 0.568) confirming the discriminant validity of AI-Based Sorting (Hussain et al., 2023; Hasan, 2025; Hu et al., 2024). The square root AVE of Data Availability is 0.760 which

is higher significantly than the correlations (from 0.543 to 0.849) confirming the strong discriminant validity (Hussain et al., 2023; Hasan, 2025; Hu et al., 2024). The square root AVE of Government Policy is 0.763 which is greater than all the correlations (0.314 to 0.676) showing good discriminant validity (Hussain et al., 2023; Hasan, 2025; Hu et al., 2024). The square root AVE of Real-Time Monitoring is 0.771, which is greater than its correlations (0.398 to 0.849), confirming its distinctiveness (Hussain et al., 2023; Hasan, 2025; Hu et al., 2024).

The square root of AVE for Automation is 0.717, which is greater than the correlations (0.509 to 0.801) and confirms the distinctiveness of Automation (Hussain et al., 2023; Hasan, 2025; Hu et al., 2024). The highest square root AVE is 0.814, which is Recycling Efficiency and its square root AVE is very high than all correlations (0.314 to 0.836) and it has the highest discriminant validity (Hussain et al., 2023; Hasan, 2025; Hu et al., 2024). Overall, these findings support the measurement model's Fornell–Larcker criterion, which states that each construct has unique variance and is linked to a specific theoretical concept (Hussain et al., 2023; Hasan, 2025; Hu et al., 2024).

Table 6: Discriminant validity (heterotrait-monotrait ratio)

Variable	AI-Based Sorting	Automation	Data Availability	Government Policy	Real-Time Monitoring	Recycling Efficiency
AI-Based Sorting	—					
Automation	0.753	—				
Data Availability	0.678	0.801	—			
Government Policy	0.568	0.676	0.451	—		
Real-Time Monitoring	0.705	0.670	0.849	0.398	—	
Recycling Efficiency	0.620	0.509	0.773	0.314	0.836	—

4.7 Structural Model Evaluation.

Another very important part of the validation process is the evaluation of the structural model.

Furthermore, the bootstrapping procedure has been applied to determine the t-values as well as R 2 values with 160 samples. The outcomes of the conventional SEM measurement were presented in Figure 2 through the Smart PLS 4.0. The external loads on all items were usually greater than allowed. Direction coefficients of most of the variables are excellent.

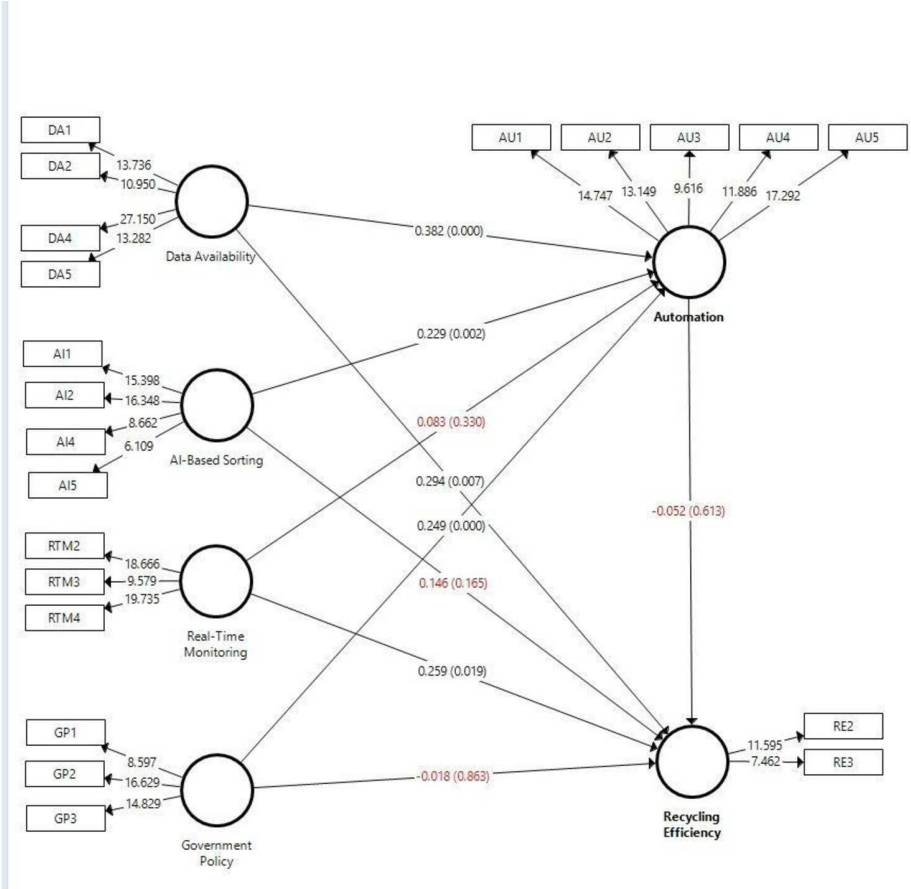


Figure 2: Standardized Results of SEM calculations.

4.8 Results of Direct Effect Hypotheses.

Results of structural model analysis on the direct effects of AI capabilities on plastic waste recycling efficiency were mixed for the eight hypotheses (Lamey et al., 2024; Sahoo & Jakhar, 2023; Sun & Wang, 2022). H1: AI-Based Sorting Automation (β = .229, p = .002) Data Availability → Automation (β = 0.382, p = 0.000) The most important predictor of automation was data availability. This is important for the access of large datasets to enable automated waste management systems (Lamey et al., 2024; Sahoo & Jakhar, 2023; Sun & Wang, 2022). Also, the Government Policy had a significant impact on Automation (H4: β = 0.249, p = 0.000). Nevertheless, the effect of Real-Time Monitoring on Automation was not significant (H3: β = 0.083, p = 0.330), indicating that continuous monitoring systems appear to have a limited direct impact on the development of automation capability (Lamey et al., 2024; Sahoo & Jakhar, 2023; Sun & Wang, 2022). Data Availability (H6: β = 0.294, p = 0.007) was most directly affected Recycling Efficiency. The data infrastructure is essential for overall recycling performance (Lamey et al., 2024; Sahoo & Jakhar, 2023; Sun & Wang, 2022). Real-Time Monitoring also had a significant effect on Recycling Efficiency (H7: β = 0.259, p = 0.019), indicating that ongoing monitoring systems result in significant operational improvements (Lamey et al., 2024; Sahoo & Jakhar, 2023; Sun & Wang, 2022). However, AI-Based Sorting was not a significant predictor of Recycling Efficiency (H5: β = 0.146, p = 0.165) and Government Policy was found to have a marginal impact (H8: β = -0.018, p = 0.863) and both failed to reach statistical significance (Lamey et al., 2024; Sahoo & Jakhar, 2023; Sun & Wang, 2022).

Table 7:Results of Direct Hypotheses Testing

Hypothesis	Relationship	Std. Beta	Std. Error	t-Value	p-Value	Decision
H1	AI-Based Sorting → Automation	0.229	0.075	3.045	0.002	Supported
H2	Data Availability → Automation	0.382	0.086	4.472	0.000	Supported
H3	Real-Time Monitoring → Automation	0.083	0.085	0.974	0.330	Not Supported
H4	Government Policy → Automation	0.249	0.066	3.744	0.000	Supported
H5	AI-Based Sorting → Recycling Efficiency	0.146	0.105	1.391	0.165	Not Supported
H6	Data Availability → Recycling Efficiency	0.294	0.109	2.712	0.007	Supported
H7	Real-Time Monitoring → Recycling Efficiency	0.259	0.110	2.352	0.019	Supported
H8	Government Policy → Recycling Efficiency	-0.018	0.105	0.173	0.863	Not Supported

It is interesting to note that Automation has not played an important role in Recycling Efficiency which needs to be discussed and interpreted in detail (Sadaa et al., 2024; Ulhasanah et al., 2024; Rahim et al., 2024). The surprising result implies the need for automation in waste management activities, but the success of recycling is not only automation, but the coordinated deployment of some AI competencies, data frameworks, surveillance infrastructure, and policy support (Sadaa et al., 2024; Li, Yang et al. (2025); Elghaish, Matarneh et al. (2022). The efficiency of recycling is a complicated and multidimensional issue not only on technological automation (Sadaa et al., 2024; Rahim et al., 2024; Chen, Xu et al. (2021). Thus, the low direct impact of Automation on Recycling Efficiency. Automation alone does not improve the efficiency of recycling but the interaction of data availability, real-time monitoring and enabling policy frameworks (Sadaa et al., 2024; Ulhasanah et al., 2024; Rahim et al., 2024). And so, means that.... The results confirm the necessity of a holistic and integrative

approach for the AI-based plastic waste recycling, not as fragmented technological solutions (Sadaa et al., 2024; Ulhasanah et al., 2024; Rahim et al., 2024).

The results have important practical implications for waste management practitioners and policymakers who want to optimize recycling operation with AI (Tűrkeș et al., 2024; Neto et al., 2023; Keskin et al., 2025). Hence, the main driving force for the efficiency of recycling should be investment in data infrastructure and real-time monitoring systems as they form the base for the successful implementation of automation (Tűrkeș et al., 2024; Neto et al., 2023; Keskin et al., 2025). The interaction of data availability, monitoring capacity and policy support implies that successful adoption of the AI requires concerted action at different organizational and institutional levels (Tűrkeș et al., 2024; Neto et al., 2023; Keskin et al., 2025). Also, further research should also investigate the indirect paths how automation affects recycling efficiency, such as data quality or enhanced monitoring abilities (Keskin et al., 2025; Neto et al., 2023; Tűrkeș et al., 2024). Together, these findings bolster the argument for systems-based solutions to deploy AI in plastic waste recycling and emphasize the need for integrated technological, organizational and policy frameworks for maximum recycling efficiency (Tűrkeș et al., 2024; Neto et al., 2023; Keskin et al., 2025).

CHAPTER 5: DISCUSSION

5.1 Conclusion

The plastic waste management industry is facing pressure with the increasing need for innovative and eco-friendly solutions to boost recycling rates. Hence, the effect of AI Based Sorting, Data Availability, Real Time Monitoring and Government Policy on Recycling Efficiency and the role of Automation in AI based recycling system was studied. The integration of technological, informational and institutional components in a single conceptual framework allows us to have a comprehensive view of the impact of artificial intelligence capabilities on recycling results. The results demonstrate the importance of Data Availability and Real Time Monitoring for the improvement of Recycling Efficiency. They highlight the need for accurate data and real-time feedback on operations in today's recycling processes. Also, the results show that AI Based Sorting, Data Availability and Government Policy are significant in Automation. This implies that successful automation adoption requires a combination of technology capacity, data availability and institutional support. Yet, no significant direct effect of the Automation on the Recycling Efficiency was observed. This means that automation alone is insufficient to improve recycling efficiency without additional technology and organizational capabilities.

The results present the AI-enabled recycling as a system rather than a set of disconnected technologies. In other words, any entity that wants to improve its recycling rates should be looking to build data-driven ecosystems that bring together smart sorting technology, monitoring systems, and automation, along with policy frameworks that support it. This tends to result in more sustainable improvements in operational and environmental performance.

The study also adds to the growing body of knowledge on artificial intelligence, sustainable waste disposal and circular economy practices, by offering empirical evidence on the factors affecting recycling efficiency. The findings provide useful insights for researchers, policy makers, waste management organizations and technology developers with an interest in the application of AI technologies to address the challenge of plastic waste and develop sustainable long-term solutions.

5.2 Implications of the Study

5.2.1 Theoretical Implications

Xuan et al. (2025), Mohsin et al. (2025), and Wu et al. (2025) emphasized the importance of exploring the role of technological capabilities in attaining sustainability outcomes. The present research contributes to the literature by showing that Recycling Efficiency is not an individual technology construct but depends on a set of technological, informational, and institutional factors. The results contribute to the current knowledge of AI-enabled sustainability by highlighting the important roles of Data Availability and Real-Time Monitoring for operational improvements in recycling systems.

Moreover, the study adds to the body of knowledge by providing a more nuanced understanding of Automation in AI-driven environments. It is widely seen that automation is a direct enabler of performance improvement. But the findings suggest that the impact of automation depends on the broader technological and organizational context in which it is embedded. Adds to theoretical understanding by showing the importance of capability integration and system-level interactions in understanding recycling outcomes. This research thus contributes to the existing literature on artificial intelligence, circular economy, sustainability and technology adoption through the development and validation of an integrated framework for understanding recycling efficiency.

5.2.2 Practical Implications

The results have important implications for waste management organizations and industry practitioners. Organizations should first invest in data infrastructure and real-time monitoring systems, before embarking on large-scale automation initiatives. The findings show that the main drivers for successful AI deployment are the basic resources of quality data and ongoing operational visibility. Without good data, sophisticated automation technologies may not be able to significantly boost recycling efficiency.

Second, managers have to take a holistic view of AI implementation. Organizations need to invest into integrated systems that make use of AI-Based Sorting, Data Availability, Real-Time Monitoring and Automation rather than one-off technological solutions. Integration helps you make better decisions, work more efficiently, and get more value from your technology investments.

These results also have important policy implications. Facilitative regulatory frameworks should be developed by government agencies to promote technological innovation and deployment of AI driven recycling solutions Policies that promote investment in digital infrastructure, technology and sustainable waste management practices will help to speed up the transition to more efficient and environmentally sound recycling systems. A collaborative approach between governments, industry players and technology providers can help to speed up the successful deployment of AI technologies in the recycling sector.

The results point out the importance of integrated solutions design for technology developers able to bridge data management, monitoring systems, automation technologies and intelligent sorting applications. Transitioning to complete platforms instead of individual technologies could improve the practical effectiveness of AI-powered recycling systems and their long-term sustainability.

5.3 Limitations and Future Research Directions

However, there are some limitations of this study; First this study is limited with cross section design which only capture the perception of the respondents at certain time. This is a useful way of looking at relationships between variables but is not useful for proving causation or change over time. Longitudinal research designs are suggested to examine the differential effects of implementation stages on AI capabilities and recycling performance.

Second, data for the study were collected through self-report survey of 160 respondents. The sample size was sufficient for the PLS-SEM analysis but future research could consider larger and more diverse samples from different industries,

regions and stakeholder groups. The more respondents you have, the more generalizable the result, and the more holistic the view on the adoption of AI in the recycling systems.

Third, only capabilities related to AI were taken into account and no other organizational and technological factors that could potentially affect the recycling's efficiency. Future research should also consider organizational readiness, technological competence, innovation capability, environmental awareness, leadership support and digital transformation maturity. Such dimensions may also help better understand the mechanisms through which AI-based technologies impact recycling outcomes.

Further research is needed to explore the indirect and moderating role of AI-based recycling system. The success of implementation can be justified by the comparison between developed and developing countries considering the role of institutional conditions, technological infrastructure and availability of resources. Further research is needed on the wider environmental, social and economic impacts of AI-enabled recycling systems including impacts on resource conservation, environmental performance and circular economy outcomes. This research would help to understand the role of artificial intelligence in promoting sustainable waste management and environmental sustainability in the long run.

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Appendix A. Survey Instrument

The Impact of Artificial Intelligence Capabilities on Plastic Waste Recycling Efficiency

Thank you for participating. This survey explores how AI technologies can improve plastic waste recycling efficiency, focusing on AI sorting accuracy, data quality, automation, real-time monitoring, and government support. The survey takes around 5–10 minutes and responses are confidential. An asterisk (*) indicates a required question.

Demographic Information

1. What is your age group? * *Mark only one oval.*

- ○ 18–24
- ○ 25–34
- ○ 35–44
- ○ 45–54
- ○ 55+

2. What is your occupation? * *Mark only one oval.*

- ○ Student
- ○ Teacher
- ○ Corporate Job Holder
- ○ Other

3. Gender *

Mark only one oval.

- ○ Male
- ○ Female
- ○ Prefer not to say

4. How familiar are you with plastic recycling technologies? * *Mark only one oval.*

- ○ Very familiar
- ○ Somewhat familiar
- ○ Not familiar at all

AI Sorting Accuracy (IV)

5. AI-based sorting significantly increases the precision of identifying recyclable plastics. *

Mark only one oval.

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

6. AI technologies reduce sorting errors compared to manual processes. * *Mark only one oval.*
   - ○ Strongly Disagree
   - ○ Disagree
   - ○ Neutral
   - ○ Agree
   - ○ Strongly Agree

7. The AI sorting system effectively differentiates between different types of plastics. * *Mark only one oval.*
   - ○ Strongly Disagree
   - ○ Disagree
   - ○ Neutral
   - ○ Agree
   - ○ Strongly Agree

8. The use of AI improves the consistency of sorting outputs. * *Mark only one oval.*
   - ○ Strongly Disagree
   - ○ Disagree
   - ○ Neutral
   - ○ Agree
   - ○ Strongly Agree

9. AI sorting contributes to reduced contamination in recycled outputs. *
   Mark only one oval.
   - ○ Strongly Disagree
   - ○ Disagree
   - ○ Neutral
   - ○ Agree
   - ○ Strongly Agree

Data Quality & Availability (IV)

10. The availability of accurate plastic waste data supports better recycling decisions. *
    Mark only one oval.
    - ○ Strongly Disagree
    - ○ Disagree
    - ○ Neutral
    - ○ Agree
    - ○ Strongly Agree

11. High-quality data is critical for effective waste management systems. * *Mark only one oval.*

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

12. Inconsistent or incomplete data negatively affects the recycling process. * *Mark only one oval.*

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

13. Access to real-time operational data enhances process optimization. * *Mark only one oval.*

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

14. Data availability supports strategic decision-making in recycling operations. * *Mark only one oval.*

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

Automation Level in Recycling Process (IV)

15. Automation increases the overall throughput of the recycling process. * *Mark only one oval.*

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

16. Higher automation reduces the reliance on manual labor for sorting tasks. *

Mark only one oval.

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

17. Automated systems provide more consistent and reliable outcomes. * *Mark only one oval.*

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

18. Automation shortens the time required to process plastic waste. * *Mark only one oval.*

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

19. Automation enhances facility capacity to manage increased waste volume. * *Mark only one oval.*

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

Real-time Monitoring & Prediction Capability (IV)

20. Real-time monitoring supports timely operational adjustments. *

Mark only one oval.

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

21. Predictive models help plan resource allocation effectively. * *Mark only one oval.*

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

22. Real-time data collection helps detect inefficiencies faster. * *Mark only one oval.*

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

23. Predictive insight strengthens future recycling planning. * *Mark only one oval.*

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

24. Real-time monitoring improves decision-making quality. * *Mark only one oval.*

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

Government Policy & Regulatory Support (MV)

25. Government policies encourage the adoption of advanced recycling technologies. * *Mark only one oval.*

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

26. Incentive programs positively impact recycling technology investments. * *Mark only one oval.*

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

27. Regulations promote higher recycling efficiency targets. * *Mark only one oval.*

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

28. Policy support increases stakeholder collaboration in recycling initiatives. * *Mark only one oval.*

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

29. Government support enhances implementation of real-time monitoring and automation. * *Mark only one oval.*

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

Recycling Efficiency (DV)

30. The recycling process significantly improves the recovery rates of plastic materials. * *Mark only one oval.*

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

31. The quality of recycled plastic products has improved over time. * *Mark only one oval.*

○ Strongly Disagree
○ Disagree
○ Neutral
○ Agree
○ Strongly Agree

32. The recycling system effectively meets environmental performance objectives. * *Mark only one oval.*

○ Strongly Disagree
○ Disagree
○ Neutral
○ Agree
○ Strongly Agree

33. Technological interventions have led to measurable improvements in recycling efficiency. * *Mark only one oval.*

○ Strongly Disagree
○ Disagree
○ Neutral
○ Agree
○ Strongly Agree

34. The current recycling process can handle different types of plastic well. * *Mark only one oval.*

○ Strongly Disagree
○ Disagree
○ Neutral
○ Agree
○ Strongly Agree