RESEARCH PAPER

A Review on IoT-Based AI Robots for Recycling and Reuse of Domestic and Agricultural Waste

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ABSTRACT

This study examines the integration of Artificial Intelligence (AI), Internet of Things (IoT), and robotics in enabling intelligent recycling and reuse of domestic and agricultural waste. Increasing waste generation and the limitations of conventional management approaches necessitate automated, sustainable solutions. The proposed framework utilizes AI-driven robotic systems supported by IoT-based real-time monitoring and data-driven decision-making to optimize waste collection, segregation, recycling, and reuse processes. A comprehensive review of recent literature highlights the role of advanced technologies such as machine learning, blockchain, and nanotechnology in improving operational efficiency, reducing environmental impact, and supporting circular economy principles. Findings indicate significant improvements in waste classification accuracy, recycling efficiency, and reductions in CO_2 emissions and energy consumption. Additionally, AI-enabled systems reduce manual labor, enhance worker safety, and enable continuous operation in hazardous environments. However, challenges such as high initial investment, data dependency, scalability issues, and technical complexity hinder large-scale adoption. Overall, the study concludes that intelligent technologies offer a promising pathway toward sustainable, efficient, and environmentally friendly waste management systems.

Keywords: Artificial Intelligence (AI), Internet of Things (IoT), Smart Waste Management, Recycling and Reuse, Circular Economy, AI-driven Robotics.

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Introduction

A growing amount of domestic and agricultural waste has become a burning environmental and social issue of concern, which requires novel and sustainable solutions. In this respect, the AI robots developed using IoT are becoming a revolutionary way of contemporary waste treatment. These smart systems are based on the ability of the Internet of Things to sense and to be connected to the Artificial Intelligence decision-making power to make the waste collection process, the waste segregation process, the waste recycling process, and the waste reuse process automated [1, 2]. Compared to the old ways of doing things that depend on the use of manual labor and in most cases lead to inefficiency in the management of such wastes, the AI-driven robotics have the ability to detect various forms of waste, adapt to diverse conditions, and execute tasks more precisely and uniformly. At home these technologies can be used to make the process of waste sorting at home simpler; at the farm level they provide effective methods of recycling of crop waste and biological waste products. These systems will not only mitigate environmental pollution by transforming waste into useful products like compost, bioenergy, and recyclable materials but they will also help in ensuring the idea of a circular economy comes into being. Hence, IoT and AI implementation in robotic waste management is an important move towards more intelligent, cleaner, and sustainable living conditions [3].

Introduction to Smart Waste Recycling Using IoT-Enabled AI Robots

The increasing issues on environmental degradation as well as the amount of waste generated by domestic and agricultural activities have necessitated the need to consider more intelligent and sustainable waste management methods. The conventional approaches of waste management that greatly rely on manual sorting and the traditional methods of disposing waste are not quite capable of dealing with the complexity and volumes of waste generated nowadays. To counter these constraints, robotization of the waste recycling process by the introduction of the IoT and AI has imposed a new paradigm on waste recycling that is popularly known as smart waste recycling. This is a strategy that aims at automating and optimizing the waste management processes to optimize efficiency, precision, and environmental sustainability [4].

The IoT-based AI robots are critical to this change as they allow monitoring in real-time, smart decision-making, and automated processes. Sensors and smart bins are examples of IoT devices that gather data associated with the type of waste, its mass, and the environment and analyze it with the help of AI algorithms. The algorithms can identify patterns, sort waste products, and identify the most effective recycling or reusing technique. Due to this, the whole process of waste management is simplified and less reliant on human factors [5]. The figure 1 illustrates an IoT-based smart waste management system where smart bins with sensors transmit real-time data to the cloud via wireless networks. This data is analyzed to optimize waste collection routes, improving efficiency, monitoring, and overall waste management operations.

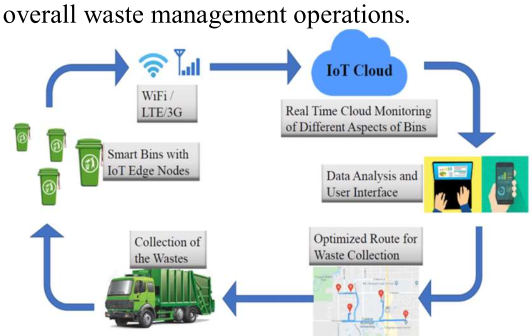

Figure 1: IoT-based smart waste system [6]

Precise and consistent waste segregation is also among the most important benefits of the use of AI-based robotic systems. These robots have computer vision and machine learning functions, which allow them to recognize various types of waste, including organic, recyclable, and hazardous, with a high level of accuracy [7]. This does not only enhance recycling performance, but also minimizes the level of contamination in the waste streams, which is one of the greatest challenges in conventional systems. Also, the robots are able to work 24 hours and in hazardous conditions that might pose danger to human employees, thus increasing productivity and safety.

In the farming sector, AI robots that are powered by IoT can provide new solutions to address the needs of large amounts of organic waste, such as crop residues and animal by-products. These systems may help in transforming waste to useful resource like compost, biofertilizers and renewable energy hence sustainable farming practices [8]. In addition, the IoT enables a more effective coordination and monitoring of the waste processing activities and efficient utilization of the resources. In general, intelligent waste recycling with the help of AI robots that have IoT is a massive step toward the issues of waste management. This strategy increases the efficiency of operations not only by enhancing connectivity, intelligence, and automation but also reducing environmental conservation and the creation of a circular economy [9].

Domestic and Agricultural Waste Generation and Its Environmental Impact

There has been an unprecedented rate of creation of domestic and agricultural waste over the past few years and this has mainly been as a result of the rapid population growth, the growing urbanization process and more intensive farming methods. With urbanization and changes in consumption patterns women generate a lot of waste such as food leftovers, plastic and paper, and other wastes in their homes. Meanwhile, the agricultural sector has a significant role in producing wastes, in the form of crop residues and animal manure, as well as food processing by-products [10]. This cumulative increase in waste in both sectors has posed great challenges in terms of effective management especially in the areas where infrastructure and awareness have yet to be established. Figure 2 represents applications of agricultural solid waste for energy, soil, and industrial uses.

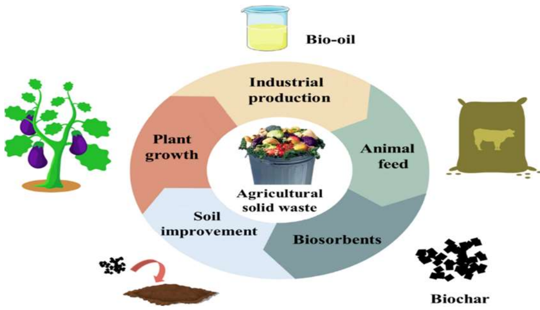

Figure 2: Applications of agricultural solid waste for energy, soil, and industrial uses [11]

This increasing waste burden has a far reaching and worrying environmental impact. Among the most evident impacts is soil pollution which is caused by the waste untreated or not properly discarded, dumping harmful chemicals and toxins into the soil [12]. Not only does this deteriorate the quality of soil, but it also impacts the yield of agriculture and the well-being of the ecosystem. Moreover, the decomposition process of organic waste in landfills produces greenhouse gases like methane and carbon dioxide which are a major cause of climate change [13]. Crop residue burning is also another agricultural activity that increases air pollution thus exposing human health and environment to health hazards.

Another serious problem that is linked to inappropriate waste management is the contamination of water. Landfills produce leachate which is filled with agricultural run-off fertilizing, pesticide and organic waste thereby contaminating rivers, lakes and groundwater sources. This not only interferes with aquatic life but fosters the supply of clean water to man and irrigation purposes [14]. Additionally, waste resources are also not fully utilized, an aspect that is a missed opportunity since most waste substances, especially organic and waste which could be recycled can be employed in production of useful products like compost, bioenergy, and reusable products. With these problems, the need to implement effective recycling, reusing, and recovery of resource methods which can convert waste to valuable resources, is on the increase. It is important to reduce reliance on landfills and reduce environmental degradation through innovative solutions that emphasize on sustainable waste management practices. Through the focus on the proper segregation, the further development of recycling technologies, and the retrieval of valuable materials, one can restore the environmental impact, as well as contribute to the change of the more circular and resource-efficient economy [15].

Integration of IoT, AI, and Robotics for Automated Waste Management

Combined with IoT, AI, and robotics, waste management systems are being redefined to become more efficient, intelligent, and adaptive. Conventional waste management systems do not provide real-time information and are too manual in their operations and may result in ineffectiveness and delays. On the contrary, IoT-based systems present an additional layer of connectivity in the form of sensors and communication technologies that would constantly check the level of waste production, the level of bin filling, the environmental condition, and the collection status [16]. These intelligent sensors acquire the data and send them in real time and make the whole process of waste management more visible and controlled. This type of flow of data in real time allows making decisions in a timely manner and ensures that the collection schedules are optimized as much as possible, which saves money on operations and eliminates the problem of overflow or wastage of resources.

The Artificial Intelligence deepens this system by converting raw information into some useful insights and behavior. Machine learning, deep learning and computer vision are AI methods that are critical to the automation of waste classification and decision-making. As an example, the computer vision models have the capability to examine images of waste material and correctly identify various types of waste e.g. organic, recyclable and hazards. The historical data can also be used to predict the patterns of waste generation and therefore the machine learning algorithms help plan the activities and allocate the resources more effectively [17]. These smart systems minimize human error, enhance accuracy of sorting and that the recyclable materials are adequately segregated in mixed waste streams. The figure 3 shows an AI-based waste management system where intelligent bins with sensors collect data and communicate with a computer-controlled system. This system enables automated waste sorting through robots, improving efficiency, reducing costs, and minimizing environmental pollution.

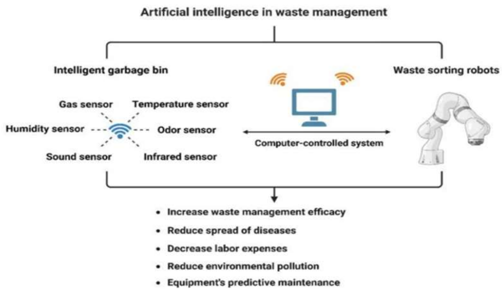

Figure 3: AI-enabled system for smart waste monitoring and robotic sorting [18]

Together with robotics, the possibilities of both IoT and AI are enhanced, and full automation of waste management solutions is achieved. The use of AI algorithms on robotic platforms may be used to perform more complicated tasks like autonomous navigation, intelligent sorting, and material handling with extreme precision. Such robots are able to go over waste collection zones, determine various kinds of waste and sort them without requiring a human supervision at all times. Also, they are able to work in risky conditions thus putting human employees at less risk, but ensuring steady output. Combining IoT with artificial intelligence and robotics, a very integrated and responsive system will be created reducing not only operational efficiency but also making waste management practices environmentally friendly. Intelligent analysis, real-time monitoring and automated execution of this integrated approach provide a complete solution to the contemporary waste issues and will help considerably to safeguard the environment and optimize the resources [19].

AI-Driven Robotic Systems for Recycling and Reuse of Domestic and Agricultural Wastes

The evolution of Artificial Intelligence has played a significant role in the evolution of smart robots meant to enhance the re-use and recycling of domestic and agricultural wastes. These robots powered by AI have higher sensing technologies and vision recognition systems, which allow them to detect various waste substances accurately, collect, and sort these materials. The techniques employed in the systems, like computer vision and deep learning can help differentiate organic waste, plastics, metals, and other recyclable materials to a significant degree of accuracy. This sorting and separation is an automated system that, besides improving the efficiency of recycling processes, eliminates the need to rely on manual workers, which is usually time consuming and liable to mistakes [20]. Artificial intelligence -based robotic systems are gradually being installed in smart waste management systems in domestic environments. These robots will be beneficial in sorting the household waste at home to make sure that all the materials that can be recycled and biodegraded are separated and disposed of in the correct way. This enhances the quality of the recyclable wastes and minimizes contamination which has been a big problem to the traditional waste management systems.

AI-based robots can be utilized in the agricultural sector to provide new solutions in handling high quantities of organic waste that include crop residues, husks and animal byproducts. The robotic systems may be applied in the processing of agricultural wastes into useful products like compost, bio fertilizers and biomass energy. As an example, the robots can harvest the crop residues in the fields and help in preparing it to compost which can be again utilized to enhance the soil fertility [21]. On the same note, biomass recovery methods with automation assistance through robotic systems would be applicable in producing renewable energy, which will be part of sustainable farming processes and would lower pollution of the environment through free burning of residues. Figure 4 shows that the implementation of AI-based robots in waste management is also associated with a number of important advantages.

Figure 4: Advantages of AI-driven robotic systems in waste management

These systems help in enhancing the efficiency of the recycling process through proper and consistent sorting of wastes to enhance the rate of recovery of the reusable materials. They also minimize the man-hand operations and therefore decreases labor costs and as well as reduces the human contact to dangerous waste areas. Moreover, waste processing is also automated which results in streamlined operations and less cost in general [22]. Above all, the technologies can help the environment to continue to exist, foster the recovery of resources, lessen the reliance on landfills, and enhance the shift to the circular economy. Figure 5 shows the Dilemmas of AI-based robotic systems in waste management.

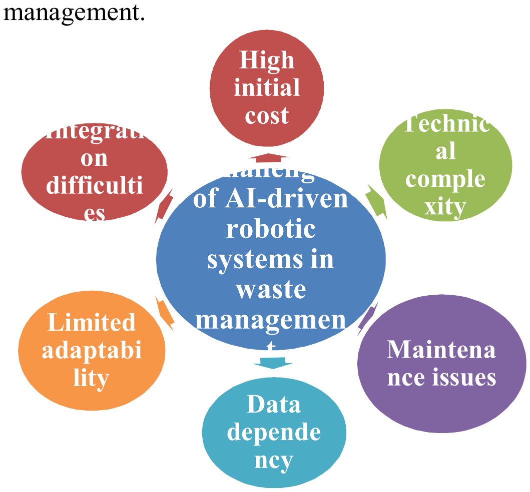

Figure 5: Challenges of AI-driven robotic systems in waste management.

Literature Review

Technological Foundations of IoT, AI, and Robotics in Smart Waste Management

One of the recent studies underscored the increased use of AI, IoT, robotics, and blockchain in changing the waste management systems. The main problems that these technologies solved included ineffective recycling, absence of real time monitoring and environmental impact, which are significant to ensure better sustainability and efficiency of operations. The integrated AI-IoT-Blockchain framework suggested by Stephen et al. (2026) [23] could streamline the process of industrial waste recycling, coal-gangue, in particular, with the problem of poor recycling and high emissions being mitigated by applying the ResNet-50-based image recognition, IoT monitoring, and blockchain traceability, with the results 95 ± 0.5% accuracy, 30% reduction in CO_2 emissions, and 34% of energy savings. On the same note, 83 studies were analyzed by Mrad et al. (2026) [24], which demonstrated that AI and robotics enhanced the efficiency of the supply chain, reducing the emission caused by the optimal path and energy-efficient warehousing, yet high energy consumption and the inability to combine all types of data remained issues. Biswas et al. (2026) [25] designed an AI-based digital twin system to handle the healthcare waste management, which will assist in enhancing the efficiency of linear waste management, and provide a substantial rise in the rates of recycling (20.0 to 50.7) ($p < 0.001$). A review of AIoT use in smart cities as conducted by Banciu et al. (2026) [26] found the application to result in waste collection, environmental monitoring, and emission reduction, but also presented issues of scalability and governance. Shahab et al. (2026) [27] examined complexities in decision-making in blockchain-based waste systems through the MCDM techniques and found blockchain-enabling tracking as the most effective one to provide transparency and compliance..

Intelligent systems have been reinforced as important in waste management by further studies. Alourani et al. (2025) [28] described a smart solid waste management system (iSSWMs) to use with IoT-enabled bins and VGG-19 deep learning to identify the type of waste; the proposed system attained 99.7% accuracy in waste segregation. The problems of low segregation and low real-time analysis were resolved when Alzahrani et al. (2025) [29] created an AI-IoT structure that would decrease landfills dependency by 30 percent and increase the efficiency of recycling to 90 per cent with 96.8 model accuracy. It was shown that the incorporation of IoT and machine learning in supply chains resulted in a lower amount of waste production and more efficient logistics, which comply with the principles of the circular economy (Fatorachian et al., 2025) [30]. A systematic review by Iyiola et al. (2024) [31] revealed some important digital technologies that include AI, IoT, robotics, as well as BIM that improved the management of waste in construction and demolition despite the existing implementation barriers. Lastly, Berigüete et al. (2024) [32] investigated how AI, GIS, and digital twins technologies could be useful in the planning of cities, so they could have better environmental monitoring and decisions, but there were still regulatory issues.

Table 1: Comparison of AI-based technologies in waste management and sustainability

Authors (Year)	Technology	Problem Addressed	Results
Stephen et al. (2026) [23]	AI–IoT–Blockchain framework (ResNet-50, IoT sensors,	Inefficient recycling, high CO_2 emissions, lack of traceability	Achieved 95 ± 0.5% accuracy, 30% CO_2 reduction, and 34% energy savings

	blockchain)		
Mrad et al. (2026) [24]	AI and robotics	Supply chain inefficiency and emissions	Improved routing and warehousing efficiency; reduced emissions, but high energy use and data integration issues remain
Biswas et al. (2026) [25]	AI-based Digital Twin system	Inefficient healthcare waste management	Recycling rate increased from 20.0% to 50.7% ($p < 0.001$)
Banciu et al. (2026) [26]	AIoT in smart cities	Poor waste collection and environmental monitoring	Enhanced waste collection and emission control; scalability and governance challenges identified
Shahab et al. (2026) [27]	Blockchain + MCDM techniques	Lack of transparency in waste systems	Blockchain-based tracking found most effective for transparency and compliance
Alourani et al. (2025) [28]	IoT-enabled bins + VGG-19 deep learning (iSSWMs)	Low waste segregation accuracy	Achieved 99.7% accuracy in waste classification
Alzahrani et al. (2025) [29]	AI–IoT framework	Low recycling efficiency and landfill dependency	Reduced landfill dependency by 30%, improved recycling to 90%, with 96.8% model accuracy
Fatorachian et al. (2025) [30]	IoT + Machine Learning in supply chains	Inefficient logistics and waste generation	Improved logistics efficiency and reduced waste, supporting circular economy principles
Iyiola et al. (2024) [31]	Systematic review (AI, IoT, robotics, BIM)	Construction & demolition waste challenges	Identified key digital technologies improving waste management, but implementation barriers persist
Berigüete et al. (2024) [32]	AI, GIS, Digital Twin technologies	Inefficient urban planning and monitoring	Improved environmental monitoring and decision-making;

			regulatory issues remain

The figure 6 presents a comparison of performance metrics from selected AI-based waste management studies. Alourani et al. (2025) achieved the highest accuracy at 99.7%, indicating superior waste classification performance. Alzahrani et al. (2025) followed with 96.8%, demonstrating high efficiency in improving recycling systems. Stephen et al. (2026) reported 95% accuracy, highlighting effective industrial waste management through AI–IoT–blockchain integration. In contrast, Biswas et al. (2026) showed a comparatively lower improvement of 50.7%, representing the increase in recycling rates using a digital twin approach. Overall, the graph indicates that AI-based systems significantly enhance waste management performance, with most studies exceeding 90% efficiency levels.

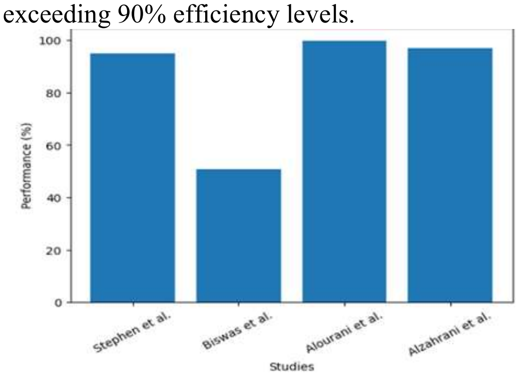

Figure 6: Performance comparison of AI-based waste management studies

AI-Driven Waste Segregation and Recycling Techniques for Domestic and Agricultural Wastes

A literature overview of recent publications provides insights into the increased use of sustainability and the principles of a circular economy, as well as advanced technologies in the form of AI, ML, and nanotechnology in overcoming global problems associated with waste management, food security, and environmental protection. The analyzed studies all underline the necessity of the innovative, data-based, and multidisciplinary solutions to reduce the negative impact of environmental degradation, increase the efficiency of resources, and optimize the working performance of many industries. Moreover, the literature reveals a shift in the linear systems towards smart, circular, and sustainable systems merging technological innovations with the right management approaches. With almost one-thirds of food production being wasted, Abbas et al. [33] recognized food loss and waste (FLW) as a global issue that requires attention with packaging, logistics, and management practices being identified as its main gaps. In the same manner, Yang et al. (2026) [34] investigated resistance to resource re-extraction in the Chinese agrifood sector and found that risk, image and usage barriers are major obstacles to the adoption of a circular system, but offers AI-based solutions, as well as blockchain and AR/VR-based solutions. The waste-based chitosan-copper nanoparticles modified by an eco-friendly nanotechnology method could be used by Atanda et al. (2026) [35] to degrade aflatoxins; they reached a degradation rate of more than 98 percent in a time of two days, confirming the promise of green synthesis..

In the construction industry, Rion et al. (2026) [36] stated that the carbon incidence is decreased by 25-45 percent with the use of hybrid industrial-agricultural materials that enhance durability and strength. Hamad et al. (2026) [37] highlighted the importance of environmental education, with models such as GPR-BOM2 having a high predictive power (R^2 as high as 0.951), having the ability to relate knowledge to pollution mitigation. The article by Archana et al. (2025) [38] and Kajda et al. (2025) [39] revealed that AI can greatly improve the efficiency of waste management, and 78% of the participants acknowledged that it reduced costs and 59% reported improved recycling. Moreover, Kajda et al. (2025) [40] offered an exhaustive SLR with the prevalence of CNN-based and hybrid models in the waste classification task, as well as revealed the limitations of datasets. Mahdy et al. (2023) [41] came up with a promising approach of utilizing faecal sludge to produce bio-crude through hydrothermal liquefaction as an alternative to energy recovery, which can be implemented in a circular economy. Lastly, Weerakoon et al. (2023) [42] emphasized on the recycling of waste materials used in the house to serve as secondary raw materials, resulting in the utilization of natural assets in a sustainable manner.

Table 2: Comparison of recent studies on sustainable waste management

Authors (Year)	**Approach**	**Problem Addressed**	**Key Findings**
Abbas et al. (2026	Supply chain & FLW manage	Food loss and waste (FLW),	Identified major gaps;

) [33]	ment strategies	inefficient packaging & logistics	emphasized need for integrated strategies to reduce ~one-third global food waste
Yang et al. (2026) [34]	AI, Blockchain, AR/VR (IRT-based analysis)	Resistance to circular economy adoption	Risk, image, and usage barriers identified; proposed AI-driven and blockchain-based solutions
Atanda et al. (2026) [35]	Nanotechnology (Chitosan–Cu nanoparticles)	Aflatoxin in contamination in food	Achieved >98% degradation within 2 days, demonstrating eco-friendly remediation
Rion et al. (2026) [36]	Hybrid industrial–agricultural materials	High carbon emissions in construction	Reduced carbon emissions by 25–45% while improving strength and durabili

			ty
Hamad et al. (2026) [37]	AI modeling (GPR-BOM2) + environmental education	Environmental pollution awareness & prediction	Achieved high accuracy with R^2 up to 0.951, linking education to mitigation
Archana et al. (2025) [38]	AI-based waste management system	Inefficient urban waste handling	Improved efficiency, reduced cost, optimized waste collection
Kajda et al. (2025) [39]	AI in waste management	High cost and inefficiency in waste systems	78% cost reduction, 59% improved recycling, better route optimization
Kajda et al. (2025) [40]	ML/DL (CNN, hybrid models) – SLR	Inefficient waste classification	CNN and hybrid models dominant; identified dataset limitations
Mahdy et al. (2023) [41]	Hydrothermal liquefaction (HTL)	Waste-to-energy conversion from faecal sludge	Produced bio-crude with properties similar to

			conventional fuels
Weerakoon et al. (2023) [42]	Waste reuse in construction	Resource depletion and waste generation	Promoted reuse of household waste as secondary raw materials

Figure 7 is used to compare the major numbers obtained in the chosen studies on waste management and sustainability. Abbas et al. (2026) point out that approximately one-third of the world food production is wasted, and it is a significant problem. Treatment in atanda et al. (2026) was very effective as the aflatoxins were more than 98% degraded using nanotechnology based treatment. Rion et al. (2026) have indicated that the level of carbon emission decreased by 45 percent, and it is an ecological advantage in the construction. Hamad et al. (2026) showed a good model performance of 0.951 in R^2 (95.1) with 78% cost reduction by AI adoption (Kajda et al.). On the whole, it can be seen that the advanced technologies contribute greatly to efficiency and sustainability as demonstrated on the graph.

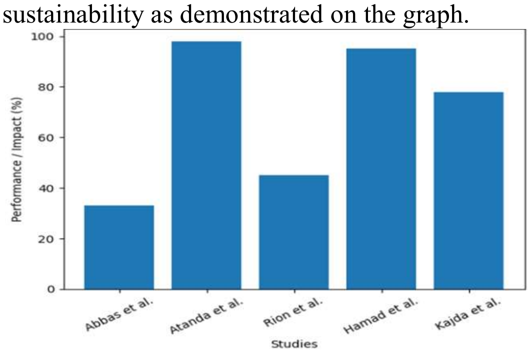

Figure 7: Performance comparison of selected studies

Performance Evaluation, Challenges, and Sustainability Impact of AI-Based Robotic Waste Systems

A systematic literature review shows that the recent changes in the waste management and sustainability guidelines are changing fast due to the incorporation of AI, IoT, blockchain, and robotics into Industry 4.0 and 5.0 models. The literature has also noted how the traditional ways of waste management have changed to intelligent, automated, and data-driven systems that are more efficient, less damaging to the environment, and contribute to the goals of the circular economy. In addition, these studies all highlight the significance of integrating the innovation of technology with operation strategies to overcome issues of resource inefficiency, emissions, and scalability of the current waste management systems. Kajda et al. (2024) [43] have shown that AI makes a major contribution to the waste management of the municipality, with 78% of the participants affirming reduced costs, 59% better recycling, and 51% better routes. Likewise, the hybrid approach suggested in Stephen et al., (2026) [44] in the recycling of coal-gangue used AI, IoT, and blockchain to obtain 95 ± 0.5% classification accuracy, 30% CO_2 reduction, and 34% energy savings, representing a high level of environmental and economic feasibility. Prasanth et al., (2026) [45] implemented a robotic sorting system with the help of artificial intelligence and WSNs and optical sensors, which was much more accurate in the sorting and efficient in working than the manual operation.

Moreover, Mrad et al., (2026) [46] described the use of Artificial Intelligence and Robotics in decarbonizing supply chains by enhancing routing efficiency and lowering emissions, notwithstanding challenges such as high energy consumption and data interoperability. In waste valorisation, De Alwiset al., (2026) [47] used state-of-the-art object detection models like YOLO and RT-DETR to reach mAP@50 of approximately 70% through detection fusion for identifying metal contaminants in wood waste. Wijesinghe et al., (2026) [48] further investigated the application of computer vision to plastic waste detection with YOLOv5 where some categories achieved more than 70% AP50, even though the overall performance was only 34.1% mAP50 under real conditions. Also, Alabdali et al., (2025) [49] suggested an AI–IoT–blockchain-based smart waste classification system that ensures secure real-time decision-making. Cheng et al., (2024) [50] described an AI-based robotic sorting system for recycling facilities that enhances efficiency while reducing labor dependency. In addition, Valeriya et al., (2024) [51] pointed out the wider effect of AI on Industry 5.0 by reporting a decrease of 12% in waste generation together with energy savings of 7%, and a reduction of CO_2 by 8%, plus better financial and employee performance. Finally, Zhang et al., (2023) [52] discussed an AI-driven framework for classifying municipal wastes and designing services which noted improvements in accuracy, efficiency as well as public engagement. All these studies prove that the coming together of AI with automation plus digital technologies is very important for making possible sustainable as well as efficient plus smart systems in managing waste.

Table 3: Comparison of AI-driven technologies for smart waste management and sustainability

Authors (Year)	**Approach**	**Problem Addressed**	**Key Findings**
Kajda et al. (2024) [43]	AI in municipal waste management	High cost, inefficient recycling and routing	78% cost reduction, 59% improved recycling, 51% route optimization
Stephen et al. (2026) [44]	AI–IoT–Blockchain (ResNet-50, sensors, blockchain)	Inefficient industrial recycling, high emissions	95 ± 0.5% accuracy, 30% CO_2 reduction, 34% energy savings
Prasanth et al. (2026) [45]	AI + Robotics + WSN + optical sensors	Manual sorting inefficiency	Improved sorting accuracy and operational efficiency
Mrad et al. (2026) [46]	AI and Robotics in supply chains	High emissions and inefficient logistics	Reduced emissions via optimized routing; challenges in energy use and data integration
De Alwis et al. (2026) [47]	Computer vision (YOLO, RT-DETR, OBB models)	Metal contamination in wood waste	Achieved ~70% mAP@50 using detection fusion
Wijesinghe et al. (2026) [48]	Computer vision (YOLOv5)	Plastic waste classification challenges	Some categories >70% AP50, overall 34.1% mAP50
Alabdali et al. (2025) [49]	AI–IoT–Blockchain system	Lack of secure and real-time waste management	Enabled real-time classification with secure data handling
Cheng et al. (2024) [50]	AI-based robotic sorting system	Labor dependency in recycling	Improved efficiency and reduced human labor
Valeriya et al. (2024) [51]	AI in Industry 5.0 sustainability metrics	High waste, energy use, emissions	12% waste reduction, 7% energy savings, 8% CO_2 reduction
Zhang et al. (2023) [52]	AI-driven waste classification framework	Inefficient service design and engagement	Improved accuracy, efficiency, and public participation

The Figure 8 compares the values of the key performance of some of the studies on AI-based waste management. Stephen et al. (2026) demonstrate the best result with about 95 percent accuracy, which demonstrates high efficiency of AI and IoT with blockchain integration. According to Kajda et al. (2024), the improvement is 78% indicating a substantial cost decrease and efficiency. On waste valorisation, De Alwis et al. (2026) reached a mAP of approximately 70 percent at 50, which is quite reliable in detecting objects. Wijesinghe et al. (2026) have a relatively worse performance of 34.1% mAP50, which indicates difficulty in plastic detection in the field. As mentioned in Valeriya et al. (2024), there was a 12 percent decrease in waste, which proves the existence of moderate yet significant sustainability gains with the implementation of AI.

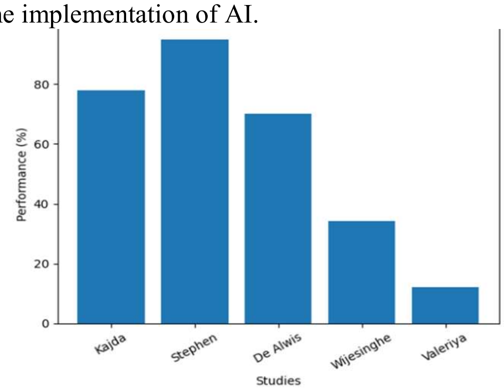

Figure 8: Performance comparison of AI-based waste management studies

Discussion

The assessed literature, as a whole, shows that the implementation of the developed technologies like AI, IoT, blockchain, robotics, and nanotechnology has immensely changed the typical linear waste management systems into intelligent, automated, and cyclic structures. The research by Stephen et al. (2026) [23, 44] emphasizes the usefulness of combined AI-IoT-blockchain systems that enhance the accuracy of waste classification (up to 95 ± 0.5% and also lower CO_2 emissions (30%) and energy consumption (34%), which is an indicator of high environmental and economic viability. In the same way, Alourani et al. (2025) [28] and Alzahrani et al. (2025) [29] show high efficiency in the segregation and recycling of waste reaching an accuracy of 99.7 and 96.8 respectively and also diminishing the landfill dependency by 30%. The need to optimize supply chains and emissions by using AI and robotics is highlighted in Mrad et al. (2026) [24, 44], but high-energy consumption and data integration remain an issue. Also, Biswas et al. (2026) [25] demonstrate that the digital twin technology represents a key improvement of the rates of recycling (20.0 percent to 50.7 percent) which supports the significance of the decision-making process which is based on simulation. All these results suggest that technology convergence plays a critical role in enhancing efficiency of operations, use of resources, and sustainability of the environment.

Moreover, some of the investigations also highlight a wider scope of implementation of these technologies in different industries, such as construction, food systems, and urban planning. As stated by Abbas et al. (2026) [33], food loss and waste are identified as one of the most important issues of a global problem, whereas over 98% aflatoxin degradation is proved in nanotechnology, which proves the importance of green innovations in protecting the environment, as stated by Atanda et al. (2026) [35]. A 25-45% decrease in carbon emissions is also mentioned by Rion et al. (2026) [36] with the help of sustainable construction materials that help adhere to the principles of the circular economy. Further, according to Kajda et al. (2024, 2025) [39, 43], AI has a positive effect on waste management performance, 78% of the costs are reduced, and recycling efficiency is improved by 59%. The highest detection accuracy of 70-percent is reported by advanced computer vision as demonstrated by De Alwis et al. (2026) [47] and Wijesinghe et al. (2026) [48], but there are difficulties with real-world application. Other research works like Banciu et al. (2026) [26], Iyiola et al. (2024) [31], and Berigüete et al. (2024) [32] point out additional problems associated with scalability, governance, and regulatory limitations. Lastly, Valeriya et al. (2024) [51] and Zhang et al. (2023) [52] show that AI-based systems might lead not only to the environmental sustainability by 12 percent waste reduction, 7 percent energy consumption, and 8 percent CO 2 emissions but also to the better economic and social performance. All in all, the literature has highlighted that even though there are immense benefits that technological advancement brings forth, it is important to take care of the implementation barriers to guarantee that the waste management system is fully sustainable and scalable.

Conclusion

As it has been emphasized in the current research, the combination of AI, IoT, robotics, blockchain, and other digital technologies has dramatically changed the nature of the traditional waste management systems into smart, automated, and sustainable models. Such superior technologies have proved to have great potential of resolving some of the most important challenges including ineffective waste segregation, absence of real-time monitoring, excessive operation expenses and environmental degradation. According to the results of numerous studies, the performance metrics increased significantly such as the accuracy of waste classification (as high as 99.7%), the decrease in the emission of CO 2 (as much as 30 percent), energy savings (as much as 34 percent), and recycling rates. In addition, AI-enabled robots have been shown to be useful in reducing human interference, enhancing operational safety, and facilitating continuous and accurate waste management at home and in the agricultural setting.

Besides this, the paper highlights how the concept of a circular economy can be applied to convert waste into useful products (e.g. bioenergy, compost, and reusable materials, etc.) to decrease the use of landfills and to enhance environmental sustainability. Although this has taken place, there are still a number of challenges such as high-initial investment, data dependency, technical complexity, integration issues and scale limitation. Moreover, issues of energy consumption, governance, and regulatory systems should be considered to be widely adopted. On the whole, the research tends to believe that the integration of AI, IoT, and robotics is a promising direction that can be followed to create efficient, smart, and responsible waste management systems. Future studies should aim at refining the adaptability of the system, lower costs and interoperability to realize the large scale application and long-term sustainability.

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