AI application for solid waste sorting in Global South

Thien-An Tran Luu, Hong-Minh Le, Minh-Quyen Vu, Bich-Van Nguyen (Văn Lang Private University, Vietnam)

Key messages

1. Artificial intelligence (AI) has a lot of untapped promise and is now applied in a variety of other sectors. Solid Waste Management (SWM) is one business that has made use of AI technology. Successful application of AI technology in SWM would help cities accelerate Sustainable Development Goals 9 and 11.
2. The application of AI technology in waste sorting, especially for inorganic waste, enhances solid waste management efficiency thanks to its higher speed and accuracy, better hygiene and safety, as well as cost-effectiveness. Nevertheless, it requires highly accurate data sources as well as high investment and operational costs, and thus may not be affordable for small- and medium-sized enterprises.
3. The following are key recommendations to encourage the application of AI in SWM:
   a. The goals of solid waste management and facilities should be developed in a systematic way so that AI could be adopted to facilitate the SWM system appropriately;
   b. Economic incentives such as preferential tax rates, tax exemptions, and duty-free tax on imported technologies and machinery would be helpful in promoting the use of frontier technology;
   c. The provision and enhancement of data accuracy could be prepared by capacity building programs for existing labor force as well as by cooperation with educational institutions for future human resource.

Solid waste management (SWM) crisis in emerging nations

Rapid urbanization, industrialization, modernization, population growth, product consumption, and economic development has contributed to an ever-increasing volume of solid waste that must be managed in countries across the world, particularly in emerging nations[1]. The infrastructure for collecting, sorting, delivering, processing, and disposing of solid waste has not kept pace with the growing amount of waste. Recent estimates indicate that solid waste generation will surge from 2.01 billion tons in 2018 to 3.40 billion tons in 2050 [2].

Current solid waste management (SWM) practices include landfilling, incineration, composting, and recycling. These SWM practices are a major contributor to the climate crisis and a source of numerous health and environmental concerns[3,4]. Furthermore, solid waste has proven to be complex, costly to recycle, labor-intensive, and a substantial health hazard to SWM employees directly involved in the waste collection and disposal[5]. Improving the SWM will reduce environmental pollution and land contamination in landfills specifically[6]. In particular, it helps reduce 50%-80% of the volume of solid waste to be buried; contributes to a decrease in SWM expenditures (assuming the classification is effectively executed, and the operating system is fully established); maximizes the reuse and recycling of solid waste resources; and reduces operating, collection, and disposal expenses of the SWM system.

In an age when recycling is increasingly important, the classification of waste is crucial [19]. Each type of solid waste has different properties that is suitable for certain recycling technologies, hence it needs to be sorted. For instance, organic waste could be recycled by composting and anaerobic digestion, while waste plastics, metallic cans, scrap paper, and waste rubber require mechanical, thermal, and even chemical processes. Issues like the habit of un-separating solid waste and lack of collection infrastructure mean that waste classification is currently facing many obstacles in emerging countries [19]. In some countries like Vietnam, although the informal sector and scavengers have participated in waste sorting in order to recover valuable waste, the waste is still not properly segregated because it is mixed with other materials such as food waste. Solid waste could be secondarily sorted at centralized stations; however, unclean recyclables are neglected. Accuracy in waste sorting is crucial in recycling different types of waste plastics and AI technology fits this purpose well [21].

Other concerns with manual waste sorting are related to hygiene and safety[8]. For instance, when separating various types of waste, waste pickers risk injury from broken glass and metal shards, as well as illness from contaminated residential and medical waste. Replacing manual waste sorting with AI technology could significantly improve hygiene and safety in the industry [19].

AI application in solid waste management

Machine learning and deep learning is currently being adopted to handle a wide variety of challenges as a result of advancements in processing power. Utilizing AI, robotic arms automatically apply Artificial Neural Network (ANN) and Convolutional Neural Networks (CNN) models (to deep learning) to sort solid waste. AI technology can be used to recycle a wide variety of inorganic wastes, including glass, plastics, cardboard, paper, metals, cartons, and cups[9]. The AMP AI platform, for example, is able to visually identify a wide variety of materials with high accuracy, and then directs fast robots to sort through and recover recyclables at speeds well beyond those of humans.

This enhances efficiency of waste sorting in terms of speed, accuracy, and cost-effectiveness [19-21]. Accordingly, the application of AI is highly recommended for sorting inorganic wastes after primarily separating them into organic and inorganic waste. The AI platform constantly educates itself to detect materials and their recyclable state by recognizing multiple colors, textures, forms, sizes, patterns, and brand labels. AI is then used to instruct robots on where to pick up and deposit recyclables. All of this occurs at a rate far exceeding that of a human being and with a degree of precision that belies its ability to operate nonstop for an entire workday. With operations in the US, Canada, and Japan (and potential future operations in the Global South), this entity may cover a wide range of locations.

AI technology reveals its contribution to SDG 11 (Sustainable Cities and Communities) established by the United Nations. The following aims to analyze the feasibilities of and propose recommendations for promoting AI technology in waste sorting in the Global South.

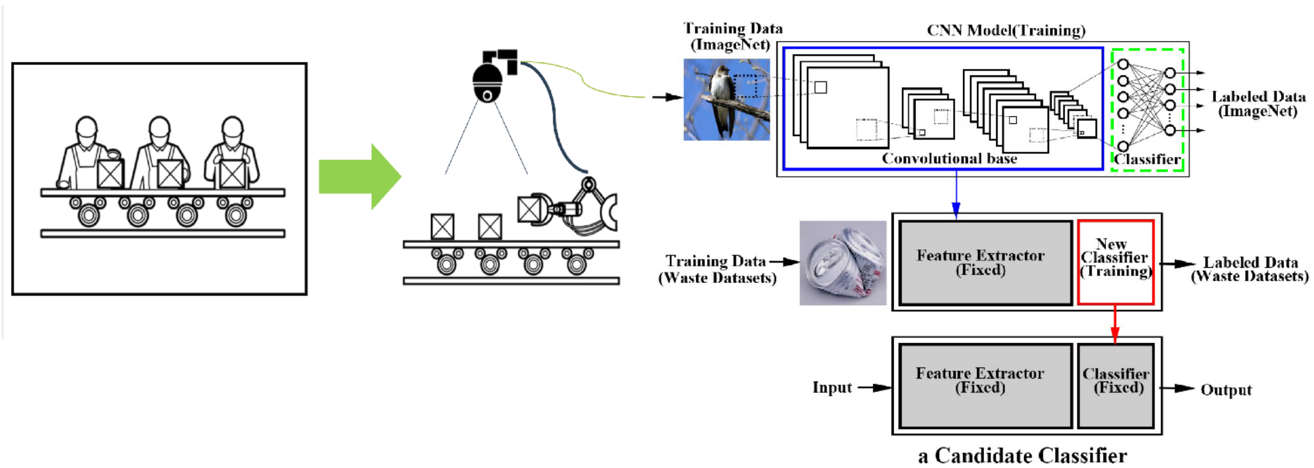

Figure 1. Switching out manual waste sorting by hand or outdated machinery for robotic coordinated AI technologies using CNN model. (CNN model from Guang-Li Huang[18]).

Feasibilities Analysis

Based on information acquired from literature, previous research, and conversations with renowned experts in the field, this policy brief examines the benefits, drawbacks, opportunities, and challenges related to the deployment and application of AI technology to classify inorganic solid waste.

Benefits versus Drawbacks

AI technology dramatically enhances the physical process of waste sorting. The use of AI with robotic arms will significantly boost the speed of waste sorting lines compared to the conventional system (line and manual sorting individuals)[19,21]. Indeed, data gathered from firms that manufacture these lines[12] as well as prior successful case studies indicate that the autonomous waste treatment line has AI integration that is two to four times more efficient than the traditional chain and can work continuously on a closed line[10]. The accuracy of the sorting process can be up to 99% with inorganic waste[7]. Although the CNN model performed well in solid waste sorting, there is still room for enhancement in the CNN algorithm's efficiency and scalability in the area of waste identification and sorting[11]. This differentiates from the previous line, which is performed by individuals with low accuracy.

In addition, specialists and literature reviews[13] revealed that AI applications can provide potential advantages. These technology advantages include an enhancement to staff assistance, a reduction in disease and health hazards as well as a reduction in effort. Minimizing direct contact with garbage sources will significantly reduce the possibility of infection for workers not only from dangerous diseases and rare accidents when in contact with garbage sources but also from respiratory diseases, and allergic reactions when exposed to waste for too long[19]. This is also a long-term and sustainable strategy if it can operate constantly for 20 to 30 years without requiring to re-employ new employees, and if ongoing learning of new data and accuracy improvement is also performed.

Despite the innovative technology, the cost of AI applications are comparable to manual sorting systems. Compared to the annual premiums of $60,000 to $70,000 that are typical for line leasing policies in the business world, the upfront cost of a line for one of these robotic arms is $250,000 to $300,000 (the cost of hiring waste sorting employees ranges from $60,000 to $70,000 per year and is equal to the price of hiring lines)[12]. Based on AMP information, financial benefits like these help governments keep recycling as a public service even as they face economic hardship and budget cuts.

However, there is also a transport and installment of equipment fee which is around 10.000-20.000 USD. Concerns about the unknown safety of AI and other developing technologies are allayed by the AMP Cortex Lease program's warranty, maintenance, and service packages.

In addition to its merits, the development and implementation of this system will have certain limitations and weaknesses. According to experts, the one-time investment for this system exceeds the financial capabilities of small and medium-sized waste sorting organizations. The cost to use this technology is high up front, making even well-funded organizations wary[12]. In order to develop this system, it is required to have a huge amount of accurate data relevant to each area and there are numerous data sources[20]. But not all data is accurate and dependable, affecting AI data learning greatly. In order to operate the system efficiently, specialists who understand both waste management and information technology are needed[20].

Opportunities versus Challenges

Regarding external opportunities, based on the issues with current waste classification system outlined at the outset of this policy brief, as well as expert commentary on the current condition of waste management in general and waste classification. The AI-powered waste sorting system has several possibilities to replace the previous system; typically, waste treatment organizations explore new technologies because waste sorting is ineffective. Since waste sorting poses health concerns to employees[12], the organization must come up with a better working line to minimize the number of sick employees who quit and damage their image and reputation. Furthermore, emerging nations which are in great need and are encouraging the adoption of new technology, lack a model or system capable of thoroughly resolving the problem of waste classification. These countries' governments are also interested and willing to invest in cutting-edge solid waste management initiatives that will assist them to maintain economic growth well into the 4.0 era[14].

Although there are numerous prospects, implementation and development of a solid waste sorting system utilizing AI would be greatly challenged. If both organic and inorganic solid wastes are to be separated automatically, these wastes must be sorted at the source or at minor gathering locations before being transported to the trash sorting plant[19]. Furthermore, employees or employers that are reluctant to change their waste sorting habits may pose another problem. The input supply for waste as well as the output for the processed product is also a challenge that is difficult to control. The adoption of this system in Vietnam is almost unachievable without a general process and numerous policies to support solid waste management. Finally, the ineffective classification of waste at the centralized landfill is a result of waste generated at the source.

Case studies

Napa Recycling & Waste Services: is a company based in the state of California that provides recycling services. The difficulties this company faces while attempting to manually sort waste are as follows: (1) Workers, no matter how well-trained, are limited in their ability to detect and collect all recyclables due to the dynamic nature of the material stream. (2) The staff cannot move fast enough to keep up with the pace at which the organization needs to generate revenue. Three AI-based classification machines demonstrate the system's benefits. Since each machine is tailored to processing a certain type of recyclable waste, this approach has helped address both the time and accuracy concerns that had previously affected the industry. Furthermore, workers have not been laid off but rather transferred to a different classification step or operate the system. Like one of the difficulties brought up by this brief, this system of AI requires a source of information, but it is extremely straightforward to upgrade, acquiring more comprehension to boost accuracy in the future, the correct size and accuracy to maximize efficiency [15].

Emmet County's Michigan MRF transports finished goods to MRFs for recycling (paper, PET plastic, etc.). Problems with line velocity and precision are also encountered. Although the problems were fixed, they required an investment of about $800,000 USD (equal to three recognitions' wages for a year) to construct three functional waste sorting systems based on AI technology. Workload decreased by 40% and processing time decreased by 60% thanks to the use of AI. By increasing the amount of recyclable waste by just 11% compared to the prior technique, sorting accuracy is considerably enhanced while processing the same quantity of waste [16]. This case study highlights the benefits of the system with regard to speed, accuracy, and cost. However, there are still many challenges to face, one of which is the human resources issue when the company is looking for skilled individuals for this system. There are insufficient resources at the institution to properly sort waste.

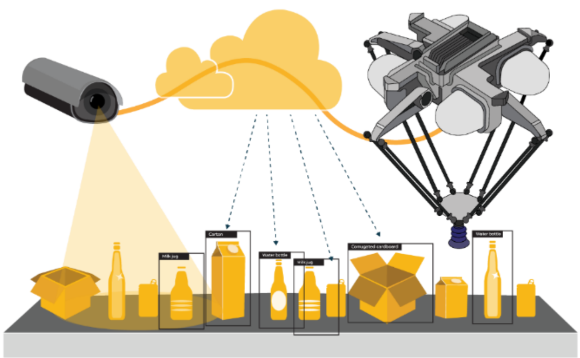

Figure 2. Simulation image of how the AI system works[9].

Policy Implications

Key policy recommendations proposed to help the Global South deploy this system are as follows:

- Initially, **goals of solid waste management and facilities should be developed in a systematic way** so that the AI could be adopted to facilitate the SWM system appropriately. Because the system is simpler to operate when waste is collected and sorted prior to being transported to the sorting plant, implementing a comprehensive SWM process will reduce the likelihood of employee resistance to change and improve the effectiveness of waste separation at the pickup location. According to the two case studies presented, the government and other authorities in the United States have developed a robust closed framework that has enabled enterprises to successfully adopt this strategy. Enterprises and the government will need to collaborate on the development of a new procedure that employs cutting-edge technologies for this to occur.

- **Policies to educate urban residents on proper waste separation to encourage a waste separation culture should be implemented**. This aids in reducing the challenges with input and mixed-up waste that hinder AI categorization. Despite the difficulty, many developed countries have succeeded in altering the attitudes of their citizens. Because their governments have provided so much support and direction, Germany and South Korea serve as admirable examples. People are aware of the numerous limitations in place to ensure proper waste segregation at the point of production. Waste4Change recommended nations with the most intriguing waste sorting processes[17]. Even if it is impossible for developing nation governments to follow this policy rapidly, they should begin the construction process gradually. The widespread installation of recycling collection stations, the design of a trash collection system based on the principle of collecting only pre-sorted waste, the use of public waste bin systems, and the practice of clearly delineating between waste streams are examples of waste separation culture.
- Enacting laws to encourage the adoption of emerging technology, especially AI and automated lines for enterprises:
    - The government might minimize the threat of the high-cost of AI waste sorting system by **offering financial assistance to small and medium-sized enterprises**. Examples of potential concrete steps include reductions in loan interest rates, import tariffs on high-tech equipment, and long-term investments for enterprises accompanied by commitments from both parties.
    - Promote the development of a cutting-edge and efficient collection, sorting, treatment, and recycling system by **adopting regulations such as organizing local government-level concept competitions for waste separation techniques and partnering with enterprises to execute the winning proposal**. Governments and environmental organizations in other nations may combine waste sorting enterprises with waste treatment and recycling enterprises to increase the output of treated waste. Firms that collaborate together to manage waste should be eligible for tax breaks or other forms of financial aid. These organizations request sector-specific support in the development of waste separation technology.
- Provision and enhancement of data accuracy could be prepared by **capacity building programs for existing labor force as well as by cooperation with educational institutions for future human resource**. In addition to data from system implementers, information can be provided by governments and environmentalists. Due to various climate and geographic circumstances, each country may have a distinct waste morphology; therefore, waste information and solid waste images assist in optimizing the database. Besides information and data, coordinating with educational centers to develop advanced technology learning programs and inter-party programs to ensure human resources will help address weaknesses and challenges faced by this system in developing countries.
- Waste management can be completed from collection to categorization and treatment with the assistance of data centers, 5G, and transportation from Government.
- **Encourage the study and deployment of automation and AI in waste classification at the plant and waste management** in general: government and social organizations can run competitions or offer awards to promote this research.

References

1. Abdallah M, Abu Talib M, Feroz S, Nasir Q, Abdalla H, Mahfood B. Artificial intelligence applications in solid waste management: A systematic research review. Waste Manag. 2020 May;109:231–46.

2. Solid Waste Management [Internet]. World Bank. [cited 2022 Dec 13]. Available from: https://www.worldbank.org/en/topic/urbandevelopment/brief/solid-waste-management

3. Coskuner G, Jassim MS, Zontul M, Karateke S. Application of artificial intelligence neural network modeling to predict the generation of domestic, commercial and construction wastes. Waste Manag Res J Sustain Circ Econ. 2021 Mar;39(3):499–507.

4. Iyamu HO, Anda M, Ho G. A review of municipal solid waste management in the BRIC and high-income countries: A thematic framework for low-income countries. Habitat Int. 2020 Jan;95:102097.

5. Goutam Mukherjee A, Ramesh Wanjari U, Chakraborty R, Renu K, Vellingiri B, George A, et al. A review on modern and smart technologies for efficient waste disposal and management. J Environ Manage. 2021 Nov;297:113347.

6. Nguyen Huu H, Nguyen Duc P. Evaluation of Municipal Waste Management Options by Circular Prevention Tools to Give Better Ways for Sustainable Transitions – A Case Study of Hanoi. Hung Agric Eng. 2019;35:45–58.

7. Ihsanullah I, Alam G, Jamal A, Shaik F. Recent advances in applications of artificial intelligence in solid waste management: A review. Chemosphere. 2022 Dec;309:136631.

8. Fadhullah W, Imran NIN, Ismail SNS, Jaafar MH, Abdullah H. Household solid waste management practices and perceptions among residents in the East Coast of Malaysia. BMC Public Health. 2022 Dec;22(1):1.

9. Artificial intelligence [Internet]. AMP Robotics. [cited 2022 Dec 13]. Available from: https://www.amprobotics.com/artificial-intelligence

10. Robotic system [Internet]. AMP Robotics. [cited 2022 Dec 13]. Available from: https://www.amprobotics.com/robotic-system

11. Liu Z, Li W, Wei Z. Qualitative classification of waste textiles based on near infrared spectroscopy and the convolutional network. Text Res J. 2020 May;90(9–10):1057–66.

12. Cai K. Rise Of The Recycling Robots [Internet]. Forbes. [cited 2022 Dec 13]. Available from: https://www.forbes.com/sites/kenrickcai/2020/11/12/rise-of-the-recycling-robots/

13. Lin K, Zhao Y, Kuo JH, Deng H, Cui F, Zhang Z, et al. Toward smarter management and recovery of municipal solid waste: A critical review on deep learning approaches. J Clean Prod. 2022 Apr;346:130943.

14. Malhotra M. Developing Countries Need New Solutions: Waste Management Rethought [Internet]. Medium. 2020 [cited 2022 Dec 13]. Available from: https://medium.com/age-of-awareness/developing-countries-need-new-solutions-waste-management-rethought-8655717d20dd

15. Napa Recycling & Waste Services [Internet]. AMP Robotics. [cited 2022 Dec 13]. Available from: https://www.amprobotics.com/casestudies/napa-recycling-waste-services

16. Emmet County [Internet]. AMP Robotics. [cited 2022 Dec 13]. Available from: https://www.amprobotics.com/casestudies/emmet-county

17. Bahraini A. Countries with the Most Interesting Waste Sorting Culture [Internet]. Waste4Change. 2018 [cited 2022 Dec 13]. Available from: https://waste4change.com/blog/countries-interesting-waste-sorting-culture/

18. Huang GL, He J, Xu Z, Huang G. A combination model based on transfer learning for waste classification. Concurr Comput Pract Exp. 2020 Oct 10;32(19):e5751.

19. Oanh Le. Interviewed by: An Le. 2022 Nov 19.

20. Binh Nguyen. Interviewed by: An Le. 2022 Nov 27

21. Chettiyappan Visvanathan. Interviewed by: An Le. 2022 Nov 30.

Appendices

Interview information

Name	Institution	Position	Interview date	Country
Dr. Oanh Le	Van Lang University	Head of Department of Environment	19/11/2022	VietNam
Dr. Binh Nguyen	Vietnam National University	Head of Department of Computer Science	27/11/2022	VietNam
Prof. Chettiyappan Visvanathan	Asian Institute of Technology, Thailand	Professor	30/11/2022	ThaiLand