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Environmental impact technology for life cycle assessment in municipal solid waste management

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ABSTRACT

Municipal solid waste management has evolved from direct disposal to recycling and resource recovery, driven by sustainability. Life cycle assessment has played a crucial role in analyzing the environmental implications of different waste management strategies and selecting the most ecologically feasible options. Establishing best practices in municipal solid waste management based on competent life cycle assessment work is essential for policymakers to make informed decisions. This study reviewed 34 life cycle assessment studies on solid waste management systems in Asian countries, examining their life cycle stages, assessment techniques, and key outcomes. The analysis highlights include functional units, various life cycle assessment models (such as SimaPro and GaBi), life cycle impact assessment methods, impact categories, and alternative waste management methods. It is necessary to prioritize recycling, resource generation (such as decomposition, incineration, and anaerobic digestion), and waste reduction over landfilling to attain a high level of environmental friendliness. However, it is essential to observe that technologies necessitating large upfront investments and skilled labor are better suited for high-income countries. Conversely, low-income countries should prioritize waste reduction through recycling, waste depots, and methods that correlate with their existing capabilities to reduce the amount of waste sent to landfills. By sharing existing methods, developing integrated municipal solid waste management systems can be accelerated in low-income nations, which can have a substantial positive economic impact. Therefore, decision-makers should consider social, economic, and environmental impacts when selecting an appropriate refuse management strategy for their nation. This analysis provides valuable insights into the scope of life cycle assessment studies and contributes to the selection of sustainable municipal solid waste management systems. These findings can be utilized by life cycle assessment practitioners, stakeholders, and Asian governments to inform policy development and decision-making processes.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
113	11	3

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INTRODUCTION

Municipal solid waste is a complex problem in many countries that impacts environmental quality and people's welfare (Charkhestani and Yousefi Kebria, 2022; Ghazali *et al.,* 2021; Zaman *et al.*, 2021). Previously, the quantity of waste production that is out of control, correlated with population growth, and its heterogeneous character has driven the shift from linear to circular economic management in waste management programs globally (Kurniawan *et al.,* 2022). The concept of sustainability is an approach that seeks to balance environmental, social, and economic aspects. In the context of municipal solid waste (MSW) generation, sustainability emphasizes the need to reduce waste generation, environmentally friendly management, and promote efficient production cycles (Bakan *et al.,* 2022; Weekes *et al.,* 2021; Kusumawati and Mangkoedihardjo, 2021; Puno *et al.,* 2021; Guerra Tamara *et al.,* 2022). Various studies show a relationship between MSW waste generation and sustainable concepts. Reducing waste generation can reduce the negative environmental impact and the need for expensive and limited landfills. Various steps such as reducing unnecessary and nondisposable packaging, reuse, and recycling, can reduce the amount of waste generated. Furthermore, environmentally friendly waste management is a key element of sustainable concept. Using technology for the types of waste to be processed such as sorting and composting organic waste, as well as applying efficient processing methods, can reduce the negative impact on the environment and produce alternative energy. To achieve a sustainable concept, involving stakeholders, such as government, private sector, civil society, and individuals, is crucial. Collaboration and cooperation between various parties are needed to develop effective policies, provide adequate infrastructure, and increase public awareness about the importance of managing waste sustainably. Asia is the world's largest continent and features rapid development. Based on a previous investigation, the urbanization rate of the typical Asian population is 3 – 4 percent (%) annually (Bren d'Amour *et al.,* 2017). Population expansion affects numerous vital aspects, including food consumption demand, economic development, urbanization, and industrialization, affecting the formation of MSW in Asian nations (Nanda and Berruti, 2021). The average MSW output in Asian countries is 4.4 109 tons per year (t/y) (Pappu *et al.,* 2011) and costs ~25 million United States Dollars annually for MSW management (Alam *et al.,* 2022), as Illustrated in Fig. 1 (Hoornweg *et al.,* 2012). Countries with a high per capita income and gross domestic product (GDP) and countries with a low GDP create more packaging waste (plastic and paper) than those with a high GDP (EPA, 2010). Meanwhile, nations with a low GDP produce more biodegradable waste (Aleluia and Ferrão, 2016).

For policymakers to determine their optimal method, it is critical to establish the best and most efficient practices for MSW management with competent life cycle assessment (LCA) methods (Iqbal *et al.,* 2020). The results of the critical evaluation are based on the LCA study with reference to the international standards used. Due to various conditions that must be met, such as technological, economic, social, and geographical. It is difficult to draw conclusions or make generalizations about the optimal technology or strategy for MSW management based on the existing conditions in each country. However, if the review's scope is broad enough to include several low- to high-income nations, the findings may offer crucial information and highlight the best approaches to adopt for long-term MSW management for general policymakers. Numerous studies use LCA to analyze MSW management, and most of these studies have three primary goals: i) to evaluate the environmental performance of particular technologies; ii) to contrast various waste treatment options; and iii) to offer useful modifications of current treatment processes to reduce associated environmental impacts (Rizwan *et al.,* 2019). Even among studies pursuing the same goal, LCA outcomes can differ due to differences in local circumstances, data sources (Steubing and de Koning, 2021), the subjective implications of various researchers, and other contributing factors. MSW management, lacking scientific rigor, may impose remarkable environmental consequences, including climate change, ecological degradation, and the depletion of natural resources (air, water, and soil) (Manna *et al.,* 2018). LCA is a method for determining the most environmentally, economically, and socially sustainable strategy for managing MSW (social LCA) (Zarea *et al.,* 2019). The LCA methodology can be used to analyze the potential environmental impacts of cradle-to-grave limits (from the extraction of raw materials to manufacturing, usage, and disposal), cradle-to-gate (extraction of raw resources to factories for production), and

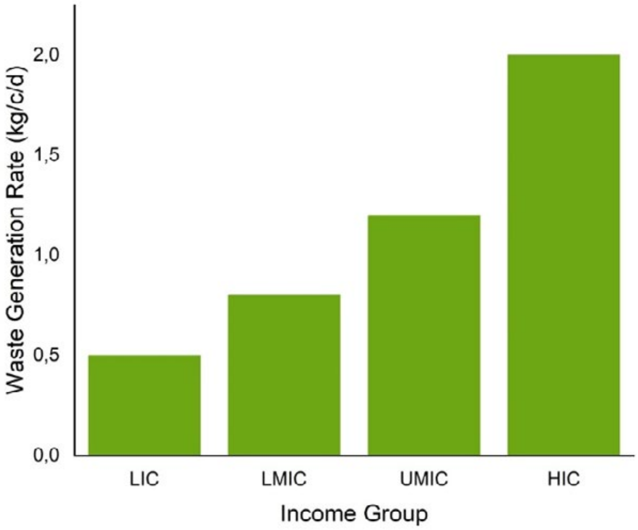

Fig. 1: Municipal solid waste generation rate in countries with different income groups (Hoornweg *et al.,* 2012)
(LICs-low-income countries, LMICs-lower middle-income countries, UMICs-upper middle-income countries, HICs-higher income countries)

gate-to-gate (reception of materials by factories to transport items created to the gate) methods, based on the requirements of each study (Abd Rashid and Yusoff, 2015). The author conducted a study on MSW management in Europe. Table 1 shows that most review studies examined certain forms of solid waste, such as paper, cardboard, plastic, biowaste, and organic waste; however, only a few studies have included all MSW management options. Table 1 shows the number of published review articles that solely discuss the LCA approach for MSW management in Europe; moreover, no research has addressed LCA in MSW management for the Asian continent. Herein, several Asian-authored scientific works on LCA for MSW management that have appeared in recent peer-reviewed journals have been critically analyzed. This study aims to achieve two goals: to evaluate best practices in MSW management with sustainable principles and to summarize systematic ideas with LCA methods for high-quality management of MSW. The results of this review can form the basis of agreement among researchers to increase the use of LCA for their practitioners in selecting methods. They will also offer indepth recommendations for better MSW management practices for adoption by policymakers worldwide based on technological, environmental, and socioeconomic factors. Table 1 shows the published review on the LCA of MSW in European countries.

METHODOLOGY

This study focused on LCA studies on MSW management involving waste generation from households, educational institutions, and industries. Using SCOPUS and Google Scholar and the keywords “life cycle evaluation of municipal solid waste management,” publications for 35 LCA studies on MSW management systems since 2013 were obtained. The processing grouping is divided into two in Tables 2 and 3. MSW management is centralized with one management method analyzed and integrated with several combinations of management, aiming to compare the most efficient methods in the management of MSW. Data were collected and analyzed using a qualitative content analysis approach, which provides an understanding of the phenomena studied and allows flexibility in analysis through visual and verbal data collection. To create an adequate assessment database regarding the environmental impact of processing MSW through LCA, the authors searched the SCOPUS database using the operator “TI-TLE-ABS-KEY (MSW and Life cycle assessment and Asian).” The studies were examined based on the following: i) the study area and the history of LCA research in the region, ii) the functional unit, iii) the system boundary and application of the LCA model, iv) sensitivity analysis, v) environmental impact categories, vi) comparisons of potential waste

Table 1: LCA municipal solid waste study in Europe

Country	Objectives of the research	References	Remarks
Croatia	Considering waste management methods in landfills to be more developed because there is no other waste management that can reduce the volume.	Hadzic *et al.* (2018)	All previously published literature reviews regarding LCA implementation in MSW management are comprehensive. Although research is limited to specific solid waste components such as paper waste, cardboard garbage, plastic waste, bio waste, and organic waste, few studies evaluate MSWM in general. Most published review articles focus on the methodology of LCA studies. Previously, LCA studies on MSW management in the entire Asian continent have not been assessed.
United Kingdom	Provides towns with a standard for operating their MSW management .	Albores *et al.* (2016)	
Scotland	Examines the evolution of LCA study methodology and the distinctions between attributional and consequential LCA methodologies.	Brander (2017)	
Central European	The findings of life cycle evaluations indicate that plastics recycling is preferable to the alternatives evaluated in this study (i.e., municipal solid waste incineration and manufacturing of virgin plastics) from both environmental and economic perspectives.	Wäger and Hischier (2015)	
United Kingdom	Provides an overview of current LCA models applicable to solid waste management (SWM).	Robert *et al.* (2018)	
Italy	Examines LCA studies of biowaste treatments, including anaerobic digestion.	Cecchi and Cavinato (2015)	
Canada	Findings show that 82 LCA studies address the management of organic wastes.	Morris *et al.* (2013)	
Germany, Denmark, France, United Kingdom, Greece, Poland, Italy	Examines the environmental effect of LCA based on studies completed in seven European countries.	Bassi *et al.* (2017)	

management strategies, and vii) the gaps and the most important findings. Conference reviews lacked the necessary peer review to be deemed a reliable source of information because they were not subject to the same standards as journal articles; viii) Old publication date: as more recent research has been done, conference reviews written before 2013–2023 may be considered outdated. The authors conducted a thorough study analysis after reading the title, citation information, abstract, keywords, and entire text to attain credibility, reliability, and believability Fig. 2.

Tables 2 and 3 summarize the MSW management methods found in all Asian countries. Each article analyzed has its own characteristics, such as the method used, the environmental impacts that occur, and the LCA model used. The functional unit of each research analyzed summarizes the red lines of the results obtained to know the management efficiency in a nutshell; all of these will be discussed in the next section. The MSW categorization adopted from various selected studies includes waste originating from cities, and various household activities, including biodegradable, construction, electronic, and composite waste (such as clothing to medical waste).

Review scheme

Critical reviews focus on the fundamental components of LCA for MSW management, such as the definition of objectives and scope, functional units, assumptions, choice of effect categories, and critical parameters/factors. These components were discovered through several LCA studies in Asia. After categorizing the research according to their unique traits and the treatment techniques used, a logical ranking of the best technology/policy was created. Recommendations and implications for optimal MSW management practices are provided based on various technological, environmental, and socioeconomic considerations.

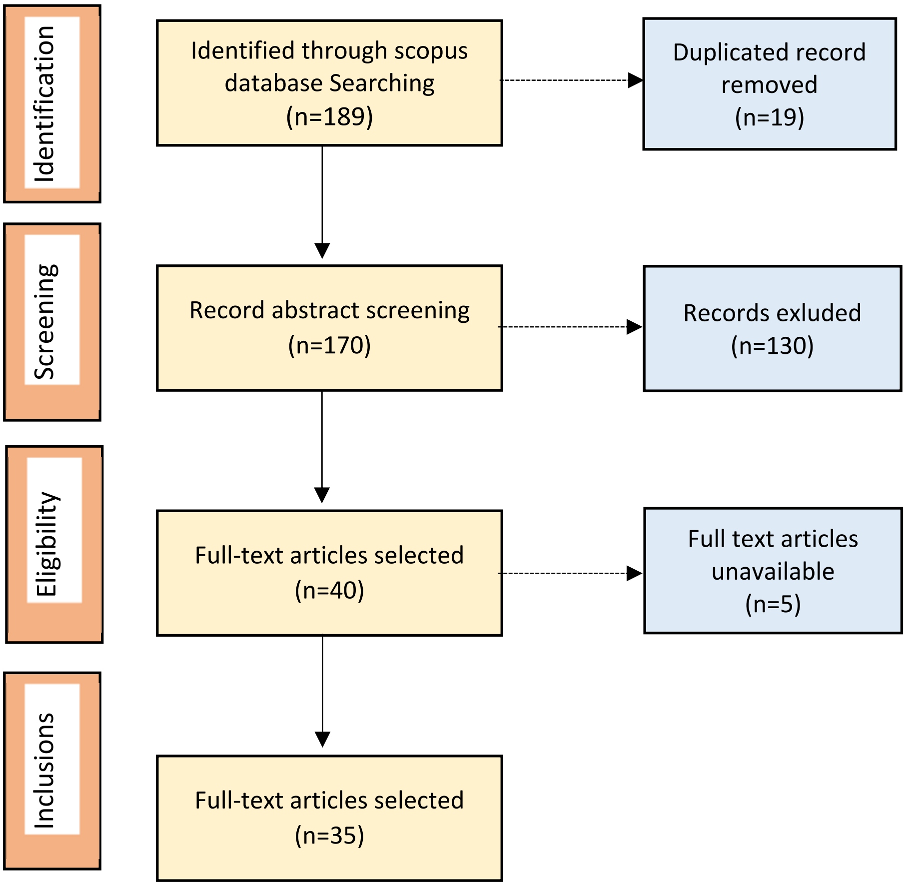

Fig. 2: Literature review method

Mapping of the study area and evolution of LCA studies in Asia

Fourteen Asian countries were identified for LCA, among which China is the largest. Fig. 3 shows the distribution of LCA studies (indicated in parentheses) selected for evaluation 1, i.e., China (11), Iran (4), India (4), Thailand (3), Turkey (2), UAE (2), and nine other countries with the same value, namely Japan (1), Lebanon (1), Indonesia (2), Qatar (1), Riyadh (1), Tehran (1), Vietnam (1), Hong Kong (1), Philippines (1). China (10) has conducted significant research in this field owing to its larger national population. Based on (Zhou *et al.,* 2014), China promptly identified and adapted to sustainable MSW management processing using LCA based on increased incineration plants in China. In 2003, there were 47 incineration plants in China, which increased to 138 in 2012.

The most LCAs were seen in 2022, while the fewest LCAs were observed in 2013, 2016, 2018, and 2021, all of which had the same amount of LCAs. The number of LCAs increased in 2013 and 2015 then decreased and remained constant from 2016 to 2018. The number of LCAs increased in 2019 and 2022, as shown in Fig. 4. No specific explanation is available for the large or small number of LCAs in any year. According to (Yadav and Samadder, 2018), fluctuations in the LCA can be attributed to issues related to waste in certain years, the level of activity within the scientific community, and the availability of functional units for MSW management-related projects. This trend in the LCA reflects the significance of using LCA to assess the environmental impacts of MSW management. Increasing adoption of LCA studies correlates with the increasing adoption of ISO 14044:2006 standards

Table 2: Excerpts from an LCA study on centralized management of MSW in Asian countries

Study location	Functional unit (FU) model and method	Scenario	Impact assessment result of parameter	Critical findings	Sources
China	FU: 1 Ton MSW Model: GaBi Method: CML 2001	S1: INC S2: Co- INC with MSW S3: Co- INC with coal S4: Co- INC in cement kiln	1. GWP 2. AP 3. EP 4. ADP 5. MAE 6. HTP	*Single incineration* is the approach that can potentially have the most damaging effects on the environment, including climate change, eutrophication, abiotic depletion, and marine ecotoxicity, when compared to the three other options for joint incineration.	Xiao *et al.* (2022)
Japan	FU: 1 Ton MSW Model: IWM2 Method: IPCC	S1: ODL S2: SLF S3: MBCS S4: KRS	1. GWP	Anyama's waste management system contributes to a rise in overall emissions. Cote d'Ivoire's solid waste management systems are not intended to create an integrated management system.	Kouassi *et al.* (2022)
Iran	FU: 1 Ton MSW Model: GaBi Method: NS	S1: COMP S2: AD S3: INC S4: MRF S5: ATT S6: LFG	1. VOC 2. SO_2 3. CO_2 4. NO_X	The model also suggests that MRFs, Incinerators, Composting, and LFGRS are the optimal facilities for managing municipal solid waste in Mazandaran's province. The study was bolstered by a cost–benefit analysis as well.	Harijani and Mansour (2022)
China	FU: 1982 Mt MSW Model: SimaPro Method: CML-IA	S1: INC: LF = 2:7 S2: INC: LF = 11:6 S3: INC: LF = 5:1 S4: INC: LF = 5:1 CO_2 Capture System	1. GWP 2. ODP 3. HTP 4. POCP 5. AP 6. EP	Increased energy recovery by producing power from incineration will be crucial to functional environmental advantages.	Liu *et al.* (2020)
China	FU: 1ton MSW Model: NS Method: NS	S1: INC S2: WWTP S3: LF S4: COMP	1. GWP	S3 was found to have the highest environmental impacts, even producing electricity.	Chen *et al.* (2020)
China	FU: 1ton MSW Model: NS Method: CML-IA	S1: WTE S2: AcRR	1. GWP 2. AD 3. POS 4. EP 5. HTP	AcRR has the most significant advantage, but some things that could be improved in the actual promotion process, reflected notably by the lack of governmental backing.	Liang *et al.* (2022)
India	FU: 1ton MSW Model: NS Method: NS	S1: ODL S2: LF, WTE S3: LF, WTE S4: BLF system	1. GWP 2. AP 3. EP 4. POCP	The bioreactor landfill option is the most advantageous of the four situations.	Sivakumar Babu *et al.* (2017)
Lebanon	FU: 1 Ton MSW Model: ESATECH Method: ILCD	S1: LF, with flaring S2: LF, Energy recovery S3: MRF (15%), COMP (50%), LF (35%) flaring S4: RCYCL (15%), AD (50%) with energy recovery, LF (35%) with flaring S5: INC (100%) energy recovery	1. GWP 2. SOD 3. FE 4. MAE 5. DAR 6. POF 7. AP	Under scenarios emphasizing recycling and composting, environmental advantages may be realized, with cost savings on emissions reaching up to 98%.	Maalouf and El-Fadel (2019)

Continued Table 2: Excerpts from an LCA study on centralized management of MSW in Asian countries

Study location	Functional unit (FU) model and method	Scenario	Impact assessment result of parameter	Critical findings	Sources
Indonesia	FU: 1kg MSW Model: Open LCA Method: CML	S1: ODL S2: INC S3: RDF	1. GWP 2. EP 3. AD 4. HT 5. ODP 6. Economy	From the three waste processing scenarios at the Cirebon cement factory, Fluff RDF is more ecologically favorable than open dumping and incineration.	Anasstasia *et al.* (2020)
Qatar	FU: 1kg MSW Model: GaBi Method: Recipe 2016	S1: LF S2: Biogas Capture from LF S3: Biogas capture and SRF gasification. S4: Biogas capture and SRF gasification with solar technology.	1. GWP 2. TE 3. MAE 4. WD 5. FD	The findings suggested that Scenario 2 reduces climate change significantly at a lesser cost than the other scenarios.	Al-Moftah *et al.* (2021)
Riyadh	FU: 1ton MSW Model: SimaPro Method: Recipe 2016	S1: LF S2: DWR S3: OWM S4: RWM	1. GWP 2. TE 3. FE 4. MRS	It has been shown that garbage recycling and waste-to-energy MSW treatments are essential for managing waste disposal difficulties and lowering the GHG emissions resulting from MSW management.	Aldhafeeri and Alhazmi (2022)
Tehran	FU: 1ton MSW Model: NS Method: NS	S1: COMP S2: RECYL S3: LF	1. GWP 2. EP 3. HT	Compared to the first scenario, the second and third scenarios lowered emissions by 64% and 72% during the second phase.	Rahimi *et al.* (2019)
Thailand	FU: 1ton MSW Model: NS Method: NS	S1: LF, WtE S2: INC	1. GWP 2. Economy	Better design (e.g., initiating LFG recovery into energy during the active phase of a landfill, using appropriate technology to extract LFG, and maximizing energy utilization by cogeneration of heat and power to be used to generate revenue).	Menikpura *et al.* (2013)
Turkey	FU: 1ton MSW Model: SimaPro Method: CML-IA	S1: Waste Separate S2: PW was not separated into 2 fractions S3: WS into 3 fractions S4: WS into 4 fractions. S5: WS 2 fractions as mixed packaging waste and glass waste. S6: WS into 3 fractions S7: WS in 2 fractions S8: WS into 3 fractions.	1. AD 2. AP 3. GWP 4. ODP 5. HT 6. PO 7. EP	According to this analysis, none of the alternative scenarios outperformed the present system. However, an ecologically superior outcome may be achieved by considerably altering the underlying assumptions, such as participation rate or material type.	Yıldız-Geyhan *et al.* (2016)
UAE	FU: 1ton MSW Model: SimaPro Method: CML-2001	S1: INC S2: GS S3: AD S4: COMP S5: BLF	1. AD 2. AP 3. EP 4. ODP 5. HT 6. MAE	Composting is the least environmentally friendly option in terms of the likelihood of creating no byproducts that may be utilized to generate electricity or replace nutrient-rich	Arafat *et al.* (2015)

Continued Table 2: Excerpts from an LCA study on centralized management of MSW in Asian countries

Study location	Functional unit (FU) model and method	Scenario	Impact assessment result of parameter	Critical findings	Sources
			7. TE 8. PO	fertilizers. However, if used in agriculture, it is beneficial.	
Vietnam	FU: 11,448-ton Mixed waste Model: NS Method: NS	S1: AL S2: SAL S3: LF Gas Capture S4: COMP S5: PC S6: Biogas Production	1. GWP 2. Economy	Landfills emit more greenhouse gases than composting and biogas generation. This is primarily due to the production and release of methane during biological decomposition in landfills.	Othman *et al.* (2013)
China	FU: 1 ton FW Model: SimaPro Method: CML 2001	S1: BBR S2: AD S3: Digestate	1. GWP 2. AP 3. EP 4. FAETP 5. HT	Identified the central pretreatment system (containing pretreatment and AD) as the most effective system on Economy Consumption and Environmental Impact.	Jin *et al.* (2015)
HongKong	FU: 1 ton FW Model: NS Method: NS	S1: LF S2: INC	1. GWP 2. Economy	AIF has a higher economic value than LFE when external expenses are considered.	Woon and Lo (2016)
China	FU: 1 ton FW Model: GaBi Method: EDIP 97	S1: LF S2: LFGTE S3: INC with WTE	1. GWP 2. AP 3. NE 4. POF 5. HT 6. ETwc	All environmental consequences diminish substantially once the gas is gathered and processed (scenario 1). Incineration (scenario 2) is superior to landfill except for problems connected to toxicity.	Dong *et al.* (2013)
China	FU: 1ton Volatile Solid (VS) Model: GaBi Method: Recipe	S1: AD for FW and Sludge S2: AD of FW S3: FW to Landfill	1. GWP 2. ODP 3. HTP 4. PO 5. TE 6. MAE 7. TE 8. MAE 9. WD	The findings suggested that the most acceptable environmental scenario for treating FW during its whole life cycle was S-2 (i.e., AD of FW).	Xu *et al.* (2015)
China	FU: 1 ton MSW Model: EASEWASTE Method: Recipe	S1: INC	1. GWP 2. AP 3. OD 4. NE 5. POCP 6. HTs 7. ECwc 8. ECs 9. HTw 10. HTa	In addition, potential improvement procedures for burning mixed, unclassified MSW were developed, resulting in excellent environmental performance.	Lou *et al.* (2015)
Iran	FU: 1 ton MSW Model: SimaPro Method: CML 2 baseline 2000	S1: INC S2: LF	1. AD 2. AP 3. EP 4. GWP 5. ODP 6. HT	The findings of a life cycle analysis reveal that incineration reduces the toxicity-related impacts of power generation and phosphate fertilizer production.	Nabavi-Pelesaraei *et al.* (2017)

Continued Table 2: Excerpts from an LCA study on centralized management of MSW in Asian countries

Study location	Functional unit (FU) model and method	Scenario	Impact assessment result of parameter	Critical findings	Sources
			7. FAE TP 8. MAE 9. TE 10. PO		
China	FU: 1 ton Model: Gabi Method: CML-IA 2000	S1: AD S2: INC WtE S3: CROESB S4: DDFD	1. AD 2. AP 3. EP 4. GW P 5. HT 6. MAE 7. PO 8. TE	Inorganic waste is treated using carbothermal reduction, and oxygen-enriched side blowing; organic waste is treated using demulsification depolymerization and directional flocculation; and kitchen waste is treated using anaerobic digestion. Household waste is also burned to produce electricity.	Chen *et al.* (2023)
India	FU: 1 ton Model: Gabi Method: Recipe	S1: GS S2: SA	1. AD 2. AP 3. GW P 4. PO	According to this comparative analysis, the foundations of alternative sorbent production seem to depend on the chosen production method rather than the material itself.	Výtisk *et al.* (2023)
Indonesia	FU: 1 ton Model: Simapro Method: CML-IA	S1: SF S2: OF	1. AD 2. AP 3. FEP 4. GW P	According to the sensitivity analysis, the main factors influencing the variance in GHG emission per ton of product were yield and the usage of organic fertilizers. As a result, it is advised that Indonesia's fertilizer recommendation system incorporate the usage of organic fertilizer.	Kashyap *et al.* (2023)
Thailand	FU: 1 ton Model: Simapro Method: Impact world+	S1: INC S2: COMP S3: LF	1. GW P 2. TE 3. PO 4. MAE 5. FE	For instance, photochemical oxidant production, which was inversely correlated with the amount of waste or distance reduced, can be lessened by onsite systems.	Rotthong *et al.* (2022)

S1, S2, S3, S4, S5, S6, S7, S8: Represents scenarios selected in respective investigations

for LCA methodologies worldwide (Khandelwal *et al.,* 2019). According to (Laurent *et al.,* 2014b), research, policy initiatives, and implementation of ISO standards have increased LCA implementation. The focus of critical reviews is the fundamental components of LCA for MSW management, such as the definition of objectives and scope, functional units, assumptions, choice of effect categories, and critical parameters/factors. These components were discovered through several LCA studies in Asia. After categorizing the research according to their unique traits and treatment techniques, a logical ranking of the best technology/policy was created. Recommendations and implications for optimal MSW management practices are provided based on various technological, environmental, and socioeconomic considerations.

Scope definition

This section analyzes the essential parts of the results obtained, including functional unit, system boundary and model use, impact category, and

Table 3: Excerpts from an LCA study on management of MSW combinations in Asian countries

Study location	Functional unit (FU) model and method	Scenario	Impact assessment result of parameter	Critical findings	Sources
China	FU: 1ton MSW Model: NS Method: NS	S1: MRF, COMP S2: INC with energy recovery S3: LF S4: RDF + INC Energy Recovery	1. GWP	Sustainable MSW management requires public education. Building accessible, supporting facilities and giving waste separation information might promote public participation in separate collections.	Wang *et al.* (2022)
China	FU: 1ton MSW Model: SimaPro Method: EPD	S1: INC S2: Mono- INC SS S3:Superimposed MSW and SS INC S4: Integrated INC of MSW and SS system	1. GWP 2. ODP 3. TET	S1 and S4 have the smallest edge of the other scenarios because implemented circular economy produces electricity.	Chen *et al.* (2019)
Thailand	FU: 1ton MSW Model: SimaPro Method: Recipe	S1: CLL, SRT+ RCYCL + ACL+LNF S2: CLL, SRT + LNF S3: LF+ RDF + RCYCL	1. GWP 2. TE 3. FAETP 4. HT 5. POF 6. PMF 7. FD	S1 landfilling had the greatest environmental effect, whereas S3 had the least environmental impact since no waste was disposed of in landfills, and RDF was introduced.	(Sukma *et al.* (2022)
Iran	FU: 292.000ton MSW Model: NS Method: NS	S1: LF, WTE S2: LF, WTE S3: COMP and LF without biogas collection; S4: RCYCL and COMP S5: COMP and INC; S6: AD, RCYCL, and LF; S7: AD and INC	1. GWP 2. AP 3. PO 4. ECT	Scenarios 6 and 7 thermal treatment and anaerobic digestion produced the most photochemical oxidants owing to significant pollution emissions.	Zarea *et al.* (2019)
India	FU: 1 Mt MSW Model: GaBi Method: CML-IA	S1: COMP & LF S2: MRF, COMP, LF S3: MRF, AD, LF S4: MRF, COMP, AD, LF	1. GWP 2. AP 3. EP 4. ADP 5. HTP 6. POCP	Analysis showed that MRF would boost environmental benefits since recycling rates lower environmental load.	Khandelwal *et al.* (2019)
India	FU: 1 Mt MSW Model: GaBi Method: IPCC	S1: ODL, BLF S2: MRF, SLF S3: MRF, COMP, SLF S4: MRF, AD, SLF S5: MRF, COMP, AD, SLF S6: MRF, COMP, INC S7: MRF, INC	1. GWP 2. EP 3. AP 4. HTP	Due to their greater energy output, incineration-based scenarios escape the most responsibilities.	Sharma and Chandel (2017)
Lebanon	FU: 1 Ton MSW Model: ESATECH Method: ILCD	S1: LF, with flaring S2: LF, Energy recovery S3: MRF (15%), COMP (50%), LF (35%) flaring S4: RCYCL (15%), AD (50%) with energy recovery, LF (35%) with flaring S5: INC (100%) energy recovery	1. GWP 2. SOD 3. FE 4. MAE 5. DAR 6. POF 7. AP	Under scenarios emphasizing recycling and composting, environmental advantages may be realized, with cost savings on emissions reaching up to 98%.	Maalouf and El-Fadel (2019)

Continued Table 3: Excerpts from an LCA study on management of MSW combinations in Asian countries

Study location	Functional unit (FU) model and method	Scenario	Impact assessment result of parameter	Critical findings	Sources
Turkey	FU: 1ton MSW Model: SimaPro Method: CML-IA	S1: LF S2: MRF, LF S3: MRF, COMP, LF S4: INC, LF S5: MRF, COMP, INC, LF	1. AD 2. GWP 3. OD 4. HTP 5. MAE 6. TE 7. PO 8. AP 9. EP	Alternative 5 is the finest choice with the most environmental advantages. Still, it may need to be more economically viable soon due to its high investment and operating expenses. Consequently, Alternative 3 may also be a viable choice.	Yay (2015)
Philipines	FU: 1ton MSW Model: NS Method: NS	S1: COMP, RCYCL, ODL, CDS, SLF, SD, OD S2: COMP, RCYCL, ODL, SLF, SD, OB S3: COMP, RCYCL, CDS SLF, SD, OB	1. GWP	Open burning of uncollected rubbish accounts for 1,628 tons of yearly emissions in British Columbia, based on business-as-usual operations.	Premakumara *et al.* (2018)

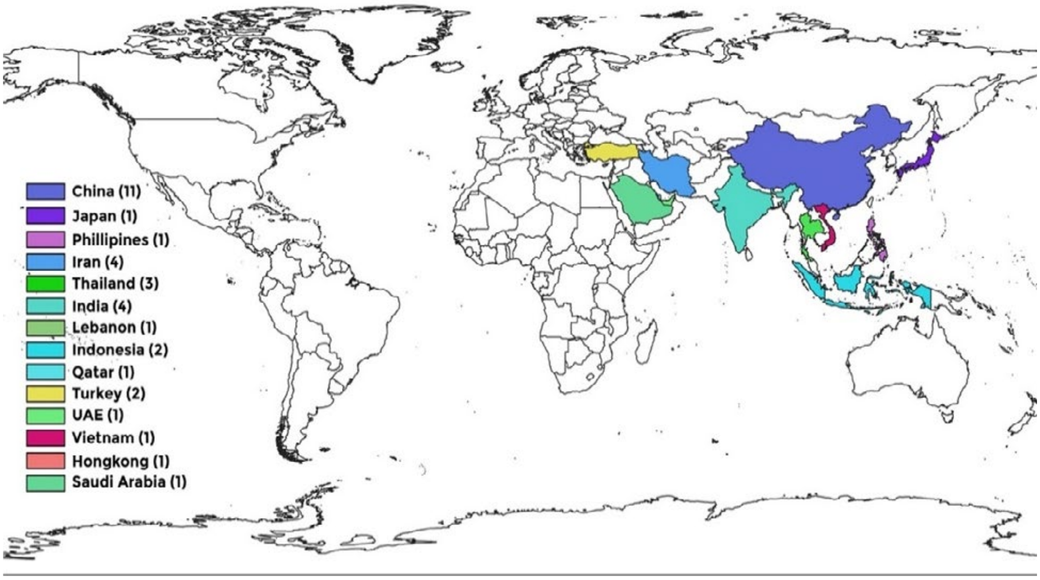

Fig. 3: Geographical distribution of selected LCA studies

sensitive parameters. These will be analyzed in more detail in the following sections.

Functional unit

The LCA approach focuses on a functional unit as the fundamental reference point. The measurable performance of the production system used as a reference unit related to the output outcomes is known as the available unit. A comparative LCA conducted using the evaluated system must provide the same functional unit; the waste capacity must be proportional to the same basis. Generally, the functional unit is the baseline for comparing analytical data (ISO14040, 2006). The often used FU in LCA research is reviewed based on the total mass or unit mass of waste, such as annual MSW generation, or

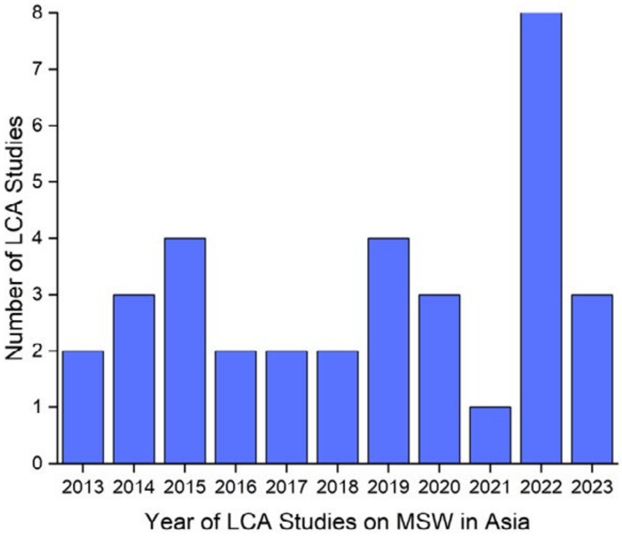

Fig. 4: Time evolution of LCA studies (2013-2023)

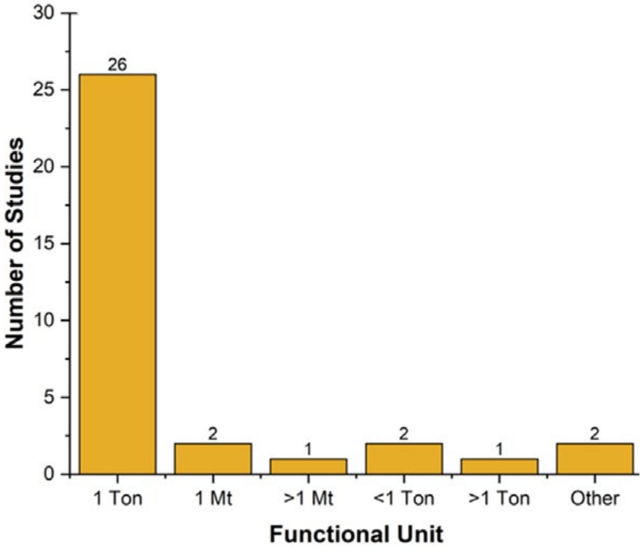

Fig. 5: Distribution of studies on functional units used.

1 t and 1 Mt generates MSW (Kaszycki *et al.*, 2021). Limiting the overall amount of garbage as FU can give a general understanding of the waste management issue today and what needs to be managed in the future to improve local waste management from an economic and environmental standpoint. The functional unit of MSW is the quantity of waste processed in the study. Fig. 5 shows the functional units obtained from the LCA experiments reported herein. The most typical functional unit was one ton of MSW (19 among 31 studies). By contrast, two studies used 1 Mt, two used 1 ton, and two used >1 Mt. Six studies on food waste (FW), volatile solids, and sludge used functional units other than MSW. The functional units were selected based on the aim and scope of the investigation. (Alhazmi *et al.,* 2021)

stated that the credibility of an LCA study relies on the definition of its aims and scope, as well as the proven functional unit. In contrast, undefined functional units result in erroneous conclusions.

System boundary and use of the LCA method

System constraints, also known as "analytical constraints," are very crucial for the initial part of the LCA method. According to Yadav and Samadder (2018), the system limit of the LCA is vital and significantly affects the overall outcome. It is defined as a processing unit that includes the operation phases, input, and output, as well as the operating time of the SWM option (Othman *et al.,* 2013). The system boundary determines the inclusion or exclusion of unit processes or variable components from the study, significantly affecting the evaluation findings (Iqbal *et al.,* 2020). The system boundaries must consider the study's duration, scope, and purpose of the study, and decisions to exclude processes or inputs/outputs must be explained (Standardization, 2006). The system constraints must ensure that all relevant processes and their possible environmental implications are considered in the evaluation. A precise system boundary definition mitigates the risk of load shifting from one phase of the life cycle to another (Laurent *et al.,* 2014a).

A model is a computer-based tool for collecting, organizing, and analyzing data; simulating waste management systems; and evaluating emissions and their environmental effects (Khandelwal *et al.,* 2019). Although conducting an LCA does not require the use of modeling software, it can help acquire, organize, and analyze inventories. Software typically for LCA, such as SimaPro and GaBi, can be used for the LCA of any product or service. The researchers chose SimaPro and GaBi for environmental impact analysis because they have various tools for characterizing and evaluating environmental impacts that can be used to examine MSW. They also have databases for raw materials, energy, and waste, allowing for the modeling and analysis of MSW throughout its life cycle (Iswara *et al.,* 2020). Other software developed specifically for LCA waste management, such as the Environmental Assessment of Solid Waste Systems and Technologies (EASEWASTE), has been superseded by a wide variety of other systems, such as the Environmental Assessment System for Environmental Technologies (EASETECH), integrated waste management, and opens LCA (Cleary, 2009). LCA analysis software is used to assess the environmental effects of solid waste management (SWM) systems. LCA entails thorough data collection on all MSW management phases, including producing raw materials, waste processing, transportation, and disposal. The general LCA analysis steps are i) Goal and scope determination: the program user chooses the analysis's goals and establishes the SWM system's evaluation's review's confines. ii) Lifecycle inventory: data pertaining to input and output are gathered and input into the software. This includes details about the quantity and kind of raw materials utilized, the amount of energy used, emissions, and other details from each process. iii) Characterization of environmental impact: the information gathered is utilized to describe how each stage of the SWM system affects the environment. (iv) Results interpretation: the results of the LCA study are evaluated to understand the relative contributions of each stage of the SWM system to the overall environmental impact. Fig. 6 shows the amount of software used in the analyzed studies. Approximately 69% of the studies used the LCA technique to simplify MSW management systems and considered the environmental benefits and costs. SimaPro was used in 28% of the studies, followed by GaBi and ESATECH, with utilization rates of approximately 25% and 6.3%, respectively. Three studies used the IWM2, EASEWASTE, and open LCA. Equations were employed to calculate the LCA, although ~31% of all studies did not use the LCA model. The appropriateness of a model depends on its price, availability, language, study goals, and user preferences (Yadav and Samadder, 2018). The choice of the LCA modeling tool depends on the research goals, tool acquisition cost, software database usage, and program usability. The LCA model is often used for environmental management systems because it has various benefits besides environmental impact analysis, namely the identification of weak points and improvement opportunities at problematic stages, allows the identification of weak points in the identified waste management system. Therefore LCA can find stages that have poor environmental impact and performance. Furthermore, this model can also be a tool for decision-makers, providing relevant and accountable information for decision-makers. By providing scientific data and analysis on a waste management system's environmental

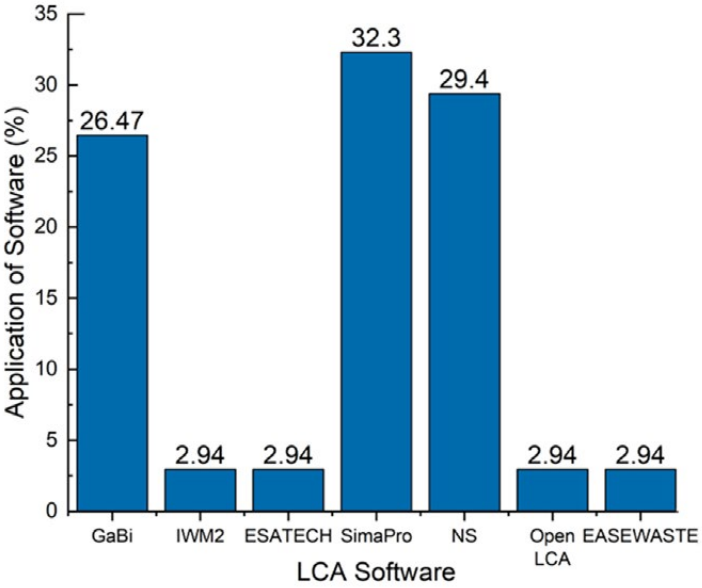

Fig. 6: Life cycle assessment software

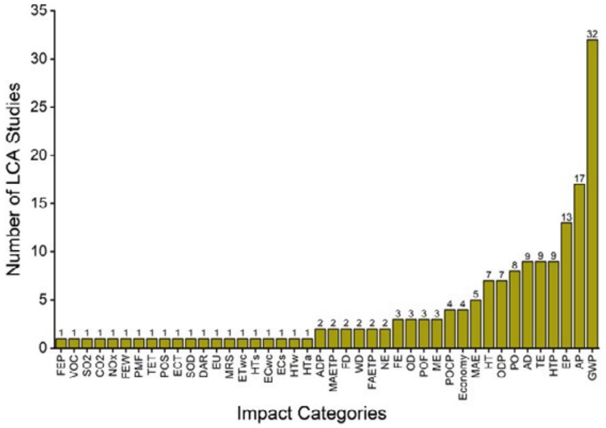

Fig. 7: Impact category

impact, LCA helps inform sustainable and evidence-based decisions. Decision-making based on LCA can consider environmental aspects and contribute to developing a more effective waste management system. Using the LCA model, an environmental management system can be developed and improved by holistically considering environmental aspects.

Impact category selection

The choice of impact categories also falls within the definition of the purpose and scope of the study. However, the broader impact categories make for a more detailed LCA analysis to lead to a sustainable system. Fig. 7 shows how often the impact categories often used in studies for technology analysis are used, with the GWP impact categories being used in impact evaluations related to climate change issues in approximately 96%–98% of the studies reviewed since the GWP is often standardized when considering the potential environmental implications (Yu *et al.,* 2022). More than half of the studies also cover potential human toxicity (HTP) and acidification and eutrophication of water resources, whereas 30% to 35% of studies cover abiotic resource depletion, ozone depletion, and photochemical ozone generation. Approximately 25% of the studies also analyzed other toxicity-related impact categories, such as possible ecotoxicity by water, soil, or water. This rarely used impact category analysis can lead to material substitution and the development of tools in the management of MSW so that it can apply sustainable principles. The study (Pratibha *et al.,* 2019) describes that the main indicators in implementing sustainable and low emissions are greenhouse gas emissions associated with climate change to analyze the impact of technology implementation applied to GWP. Furthermore, energy use to measure the total energy used in each life cycle of the technology used, high energy use can show a significant impact on natural resources and greenhouse gas emissions. The use of natural resources is also an important indicator, which evaluates the use of water, raw materials, and other materials used in implementing technology; excessive use of natural resources can cause a high reduction in crucial natural resources. The formation of waste is also an indicator that is no less important because an increase in the amount of waste produced can indicate problems in process efficiency and efforts to reduce waste, recycle and reuse materials. Air and water emissions are the most frequently used indicators after GWP in accordance with the research results conducted because this indicator includes emissions to air and water produced by the implementation of technology. Examples of emissions produced are in the form of particulates, heavy metals, liquid waste, and various other emissions, which can flow in bodies of water or in the air that is inhaled. From this, indicators of poisoning and health risks are included herein because these indicators can evaluate the potential for poisoning and health risks associated with technology implementation.

Key sensitive parameters

The primary sensitive characteristics are typically based on the current state of the area to be investigated and the availability of technology based on the current state of affairs. However, additional parameters are frequently introduced in the studies under consideration (Elkadeem *et al.,* 2019, Talal *et al.,* 2019). Studies that do sensitivity analysis frequently apply the substitution factor for electrical energy to promote sustainable concepts, as observed in 45%–55% of the papers analyzed. In addition, the composition of MSW, effectiveness of recycling into new products such as compost and animal feed, and energy production/recovery rate from incinerator methods that produce novel resources such as electricity are the most commonly used parameters, with a relatively high level of representation for sensitivity analyses. As shown in Fig. 8, numerous

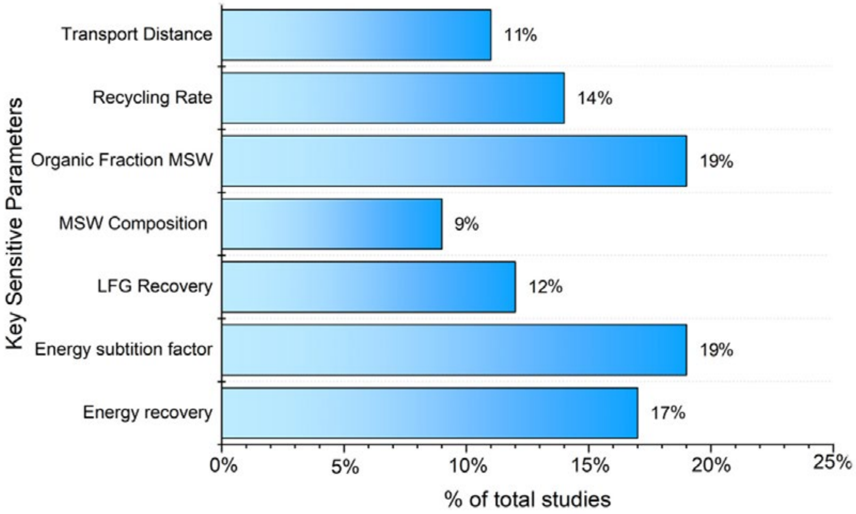

Fig. 8: Key sensitive parameters, the research that has been looked at and used sensitivity analysis has identified and thoroughly detailed key sensitive parameters that significantly affect the final results

other studies also employed the amount of organic waste in MSW, hauling distance, substitutes for recovered materials, and effects of biogenic carbon are examples of emission and sequestration variables. Among other characteristics, the water content in MSW, MSW's calorific value, and anaerobic digestion (AD's) ability to produce biogas are frequently utilized in research to increase the sensitivity of the analysis.

Sensitive criteria importance best fo MSW

Information on the specified subprocesses, the technology used, and the geographic and socioeconomic context are used to determine the effectiveness of MSW management (Iqbal *et al.,* 2020, Rotthong *et al.,* 2022). As explained in the previous section, sensitive parameters are key in the system being analyzed to have a major influence in assessing the potential environmental impact of a technology/policy (Dong *et al.,* 2022, Harun *et al.,* 2021). For example, the composition of MSW varies greatly from country to country and is most important in all aspects due to the existing conditions and habits of the people (Awasthi *et al.,* 2022, Ramos and Rouboa, 2020). This impacts crucial elements that impact on emissions, including heating value, moisture content, the proportion of organic and inorganic debris, etc. (Sgarbossa *et al.,* 2020, Mayer *et al.,* 2020). Regarding the potential for energy and resource recovery as well as environmental emissions, this metric is crucial for all processing processes (Razzaq *et al.,* 2021, Jaunich *et al.,* 2020). The composition of MSW may therefore indicate integrated approaches for separation, recycling, or processing in MSW management (Wang *et al.,* 2022, Paes *et al.,* 2020). For instance, waste with a high organic content can be treated again for new materials and energy recovery (composting, AD, etc.). The content of the MSW can help decide the optimum integration strategy because some products made of metal and plastic can be recycled and utilized as raw materials, such as in the production of concrete. Technology's ability to recover energy and energy replacement variables are crucial, and they may differ between places depending on available technology, environmental factors, fuel blending techniques used in local energy production, and newly discovered energy resources. (Ding *et al.,* 2021, de Sadeleer *et al.,* 2020). Therefore, technologies that are more attractive because of their high energy recovery potential, such as incineration and AD, depend heavily on these factors (Pheakdey *et al.,* 2023). Without energy recovery, this technology is not very attractive and has high side effects such as environmental impact, especially for incineration because of its high cost and emissions (Pheakdey *et al.,* 2023, Hoang *et al.,* 2022); therefore, for the optimum MSW treatment, methods other than incineration will be considered. Like the preceding illustration, energy recovery technology's environmental benefits are lessened if energy is produced using methods based on sources cleaner than fossil fuels, such as hydropower. (Siwal *et al.,* 2021) such as incineration or landfill technologies that produce new energy. The same is true for recycling methods and material substitution factors. Stakeholder policies must consider the supply and demand for recycled materials because the market often uses new materials due to quality problems (Hermansson *et al.,* 2022, Tonini *et al.,* 2022). Countries with high per capita income show competition between recycling and energy recovery methods, to be observed because it has a higher calorific value (Halkos and Petrou, 2016). As a basic example, plastic and cardboard are one of the main raw materials for combustion in energy production by the incineration method. However, if the criteria for being a raw material for incineration are not met, in that case, they can be recycled for use as other raw materials or molded or made into other forms. Energy recycling and recovery techniques for MSW management are an efficient combination and should complement each other based on local demand. Other factors include the transportation distance from the collection point to the management facility, which is also crucial in various regional conditions. Because the new policy may involve other techniques suitable for MSW, increasing the frequency and distance of transport can have direct environmental and socioeconomic impacts that are not foreseen (Omer, 2010). Before choosing the most effective MSW management strategy in these circumstances, LCA experts and policymakers should discuss a thorough assessment of the technical elements and local conditions that influence them. Subjectivity in evaluating environmental protection, cost of capital, and societal acceptance vary between low and high-income countries so that it can generate technological or policy choices that benefit society and the environment.

Guideline for best practices for MSW management

Various variations in technological developments, the geographical characteristics of the country as well as the population's socioeconomic situation, conclude that it is difficult to apply a centralized method or policy in MSW management in various regions (Vance *et al.,* 2022, Baustert *et al.,* 2022). These variations necessitate adjusting the application of the technology required for effective MSW management. Additionally, a nation's weighted preferences in relation to shareholders are used to determine which management technique to implement. For the optimum implementation of MSW management for policymakers, however, critical and valuable implications are required based on the critical analysis of numerous scientific studies from developing to developed Asian nations. Crucial considerations in MSW selection can help address challenges associated with greenhouse gas emissions, resource depletion, and emissions arising from MSW management technologies. Some methods used in overcoming this problem, such as MSW Technology, can involve recycling and energy recovery processes from waste. Recyclable materials such as paper, plastics, metals, and glass can be coated by efficiently separating and treating waste, reducing the demand for new raw materials and the emissions associated with new production. Composting, the application of efficient composting technology in MSW management, allows for the controlled treatment of organic waste and the reduction of methane gas emissions while producing a valuable and sustainable product in the form of compost. Furthermore, approaches such as pyrolysis technology, gasification, or other processing can handle difficult waste that cannot be thermally reproduced. This process can convert waste into alternative fuels, gases, or chemical products that can be used in industry, reducing resource depletion and associated emissions. Implementing a sophisticated monitoring and control system can aid in monitoring and controlling emissions and pollution caused by the management of MSW. Corrective measures can be taken with accurate monitoring to minimize negative environmental impacts.

Reviewed technology

Various existing conditions and new technologies have diverse the technologies used in MSW waste management worldwide. The type of technology and the number applied from the various studies reviewed is shown in Fig. 9. It is evident that technologies have advanced from landfill to more advanced treatment methods like engineered backfill to generate electricity, as well as multiple thermal and biological processes with resource recovery systems, from the source to waste separation, recycling, treatment, and final disposal. Overall, these results cover both centralized methods and scenarios involving MSW management methods analyzed by LCA experts in potential environmental impact assessments.

Best MSW management technologies/facilities

The purpose of selecting all studies from a total of 34 that were analyzed was to identify the best MSW management technology in terms of environmental sustainability for handling MSW. This classification is done to make objective comparisons between various waste management scenarios and get reliable results. The classification of the reviewed research indicates that the optimal scenario for managing MSW in terms of sustainable development is represented by Fig. 10. It can be seen that more than half of the studies analyzing the combination of technologies concluded that an integrated MSW (IMSW), i.e., integrating several technologies to manage MSW, is the best-case scenario in terms of MSW management and an eco-friendly concept (Asefi *et al.,* 2020, Weihs *et al.,* 2022). The summary results obtained from Table 2 and Fig. 9 explain that the use of a single centralized technology in the management of MSW as in traditional practice has relatively low efficiency; technology integration with a combination of several methods is the best approach to develop environmentally friendly principles (Arabi *et al.,* 2021, Colangelo *et al.,* 2021). An integrated approach with several methods helps to achieve efficient and environmentally friendly waste management practices, such as recycling of goods, resource recovery, and reducing the amount of final waste disposed to landfills which can pollute the environment more highly. This principle is in line with research (Saha *et al.,* 2021, Lai *et al.,* 2022) which analyzes the potential environmental impact of several new technological references such as pyrometallurgy, hydrometallurgy, biometallurgy in the management of MSW and combination of old methods such as LF, COMP, MRF and AD to obtain a combination method that has better advantages and higher management efficiency (Lai *et al.,* 2022, Saha *et al.,* 2021, Tabelin *et al.,* 2021).

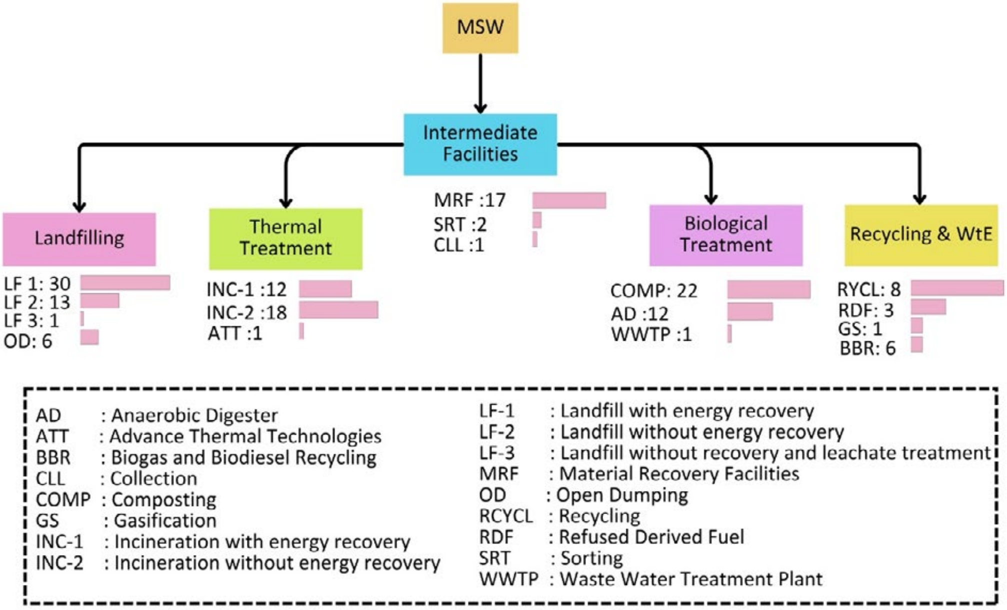

Fig. 9: Types and quantities of MSW treatment technologies under evaluation (Iqbal *et al.,* 2020)

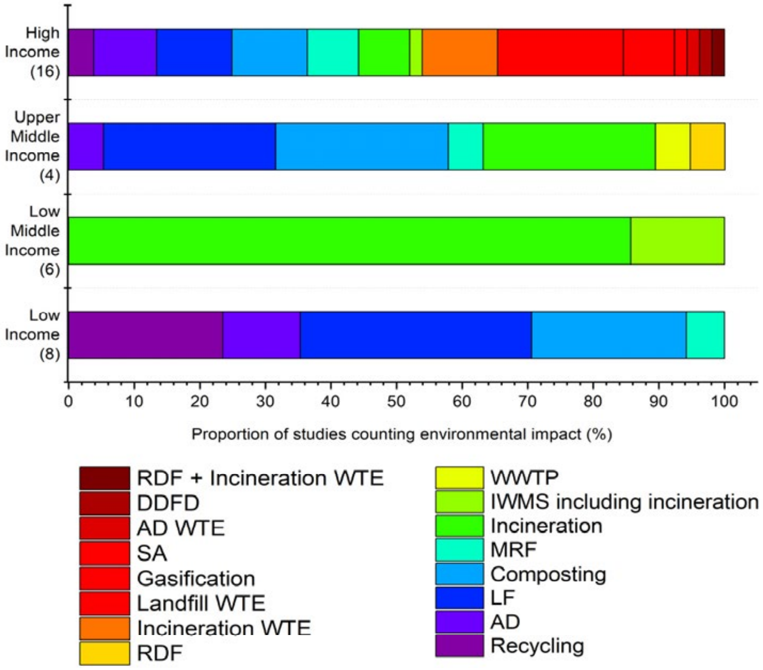

Fig. 10: Proportion studies counting the environmental impact

IMSW technology is used to measure and evaluate the environmental impact associated with the stages of MSW waste management. Examples of how IMSW can be used at each stage are; i) Collection and transportation waste generation measurement technologies and collection route monitoring can be used to estimate the volume and composition of waste collected; ii) Processing and sorting, used to identify the type of waste that goes into processing and segregation, thereby facilitating a more effective sorting process; iii) Recycling and energy recovery involving the use of identification and classification to separate recyclable materials from combined waste to produce compost and electricity; iv) Integrated technology with sensors for remote monitoring of IMSW applied to landfills to detect and reduce methane emissions; v) Utilizing data and analytics, as well as analytics technology to support IMSW, can be used to monitor and evaluate waste management performance, identify potential enhancements, and strengthen decision-making based on evidence. IMSW can provide more precise and comprehensive data regarding the environmental impact of each MSW waste management stage by utilizing sensors, monitoring, data analytics, and simulation software. This allows for wiser decision-making and more effective waste management actions. For example, an ideal MSW management could consist of a combination of methods such as recycling (centralized source or segregation) to separate organic and nonorganic waste, biological treatment (AD, COMP) to process organic waste into new materials or resources, as well as incineration (with energy recovery and concrete), stockpiling (with leachate collection and LFG systems) as the final part of MSW management. Technology such as advanced incineration facilities that generate energy requires large initial capital investment, operating and maintenance costs, and a skilled workforce in implementation, making this method unfeasible for low-income and lower middle–income countries. Conversely, low-income countries may replace MSW management without incineration but should develop schemes that promote the recovery and recycling of MSW's inorganic and organic fractions of MSW. One of the main causes of landfill pollution is the enormous and diverse volume of organic waste that makes up MSW in both industrialized and developing nations. Therefore, recycling organic waste by biological technologies (AD and/or composting) has the benefit of recovering resources (energy/compost), significantly reducing pollution, and reducing the amount of landfill space needed, allowing for effective use of the output generated (Van Fan *et al.,* 2020, O'Connor *et al.,* 2021). Social issues, including political will, job creation, public annoyance (noise, odor, traffic intensity), occupational health, etc., can also affect how local stakeholders, like the government, businesses, and citizens, implement policies. The application of advanced technology/ideal scenario compared to conventional methods was chosen from the various methods analyzed because it has a relatively low environmental impact. Applying the method due to the emission of greenhouse gases can reduce these emissions significantly compared to the traditional method of open burning and stacking in landfilling. Furthermore, reducing emissions into the air and soil, Traditional waste management often involves direct discharge to the environment, which can cause water and soil contamination. In a systematic MSW system, waste is treated more controlled and can reduce the risk of water and soil contamination. Advanced technology can utilize energy and resources. Such advanced waste management technologies can harness the energy contained in waste, such as methane gas produced from anaerobic digestion. This energy can drive turbines or electric generators, reducing dependence on fossil energy sources and associated carbon dioxide (CO_2) emissions. Finally, the absolute advantage is a significant reduction in waste volume without needing large space for stacking. Even though advanced technology has integrated stages, it always produces final waste that needs to be disposed of in a landfill, so it has problems in the form of managing and transporting waste from sources to landfills which causes problems in the form of air pollution from the use of trucks and other vehicles from the fossil fuels used. Ecosystem damage due to inappropriate waste disposal, such as illegal dumping, can disrupt the lives of living things. By implementing the right technology, such as automated sorting systems, industrial composters, or recycling facilities, IMSW technology can help reduce the negative impact of waste transportation and disposal on the environment.

Gaps and the critical findings on the aplication of LCA MSW management *in Asian Countries*

Fig. 10. illustrates the MSW management technique used throughout Asia. Landfilling is a practice that is

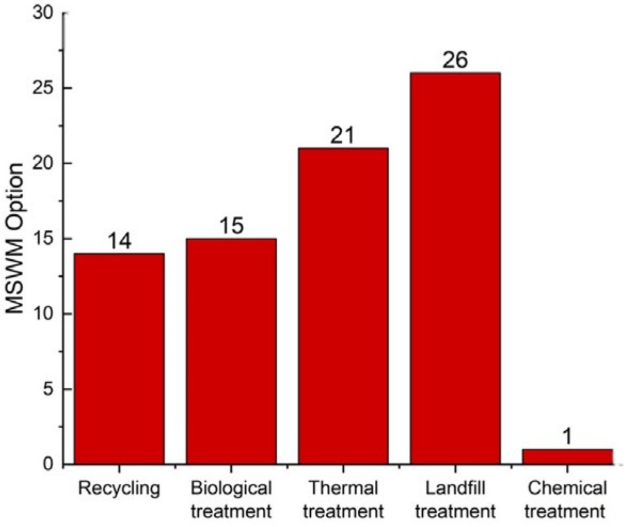

Fig. 11: Suitable MSW management options

widely used and is not environmentally friendly, even though it produces sustainable management. The results of integrated management are very efficient but expensive; hence, hoarding remains the preferred option (Khandelwal *et al.,* 2019). MSW disposal techniques such as landfilling and open burning significantly affect the amount of methane gas produced, significantly affecting human health and environmental sustainability (Premakumara *et al.,* 2018, Cogut, 2016a). One-third apply scenarios using landfilling without further management and open burning for handling MSW, and most are based in LMI countries; this is because integrated management cannot be carried out due to the relatively high cost of producing new resources such as electricity from the incineration method (Menikpura *et al.,* 2013, Ferronato and Torretta, 2019). Fig. 8, as presented in Tables 2 and 3, illustrates the many uses of MSW to make waste into an energy source during the previous decades. To create energy, most of the studies continue to use incineration scenarios with relatively high initial investment. In contrast, only 12 and one study use LFG and gasification scenarios, respectively, due to technological limitations and relatively higher investment in incineration methods due to LFG implementation, which requires various technologies in gas absorption. However, the benefits of this method can be maximized because the gas that arises from the landfill can operate the landfill itself and several surrounding buildings, as was done by (Alzate-Arias *et al.,* 2018, Khandelwal *et al.,* 2019) utilizing LFG to run the landfill and the Federal Bureau of Prisons' Allenwood Correctional Complex. Based on investigations into converting landfill gas into energy, several studies have shown that landfill management can be the optimal solution (Manasaki *et al.,* 2021, Kormi *et al.,* 2017). Furthermore, countries that still use the MSW management technique followed by a combination of recycling and composting or combined and classified as the deepest IMSW get better waste management with minimal or without environmental impact (Safar *et al.,* 2021, Amin *et al.,* 2023). Most studies demonstrated that biological treatments, such as composting and anaerobic digestion, are more beneficial than thermal treatment and landfill. Similarly, most of the 40%–47% of studies analyzed using combined methods fall under IMSW due to the heterogeneous nature of the municipal waste (Njoku *et al.,* 2018, Srivastava and Chakma, 2020). One ideal stage not covered in various cited journals is reducing waste at its source. To handle this, several strategies can be used in the form of reducing packaging practices, avoiding products with excess packaging or using alternatives in the form of recyclable packaging; prioritizing the recycling of materials that can still be used in the form of plastic, metal, and glass; take advantage of available garbage programs even with minimal infrastructure resources; encouraging innovation and environmentally friendly technology.

RECOMMENDATION

As a comprehensive strategy, IMSW incorporates several waste management techniques, such as waste reduction, recycling, composting, and controlled disposal. Composting is the most effective recommendation for treating household and green waste from plants and gardens. It produces organic fertilizer useful for agriculture and horticulture. Thermal processing, such as pyrolysis and gasification, can convert energy into new forms, such as gas, oil, and electricity. Hazardous waste management infrastructure is crucial to prevent hazardous waste from polluting the environment. It includes safe collection and processing facilities for waste in the form of batteries, hazardous chemicals, and electronic waste. The IMSW method shows very efficient results for MSW management, but these results can only be applied to countries with relatively high incomes. The successful implementation of IMSW in high-income countries can be supported by several important factors in the form of adequate policies and regulations; a solid legislative and regulatory framework for MSW waste management comprises mandated recycling, waste reduction, hazardous waste management, and complex structures; includes strict waste management standards, permits, and monitoring. Additionally, a “high-income country” must have adequate infrastructure in MSW waste management, including efficient waste collection, cutting-edge recycling centers, and energy recovery facilities. This method promises to be effective, efficient, and environmentally friendly, with outputs in the form of renewable energy and minimizing negative environmental impacts. The IMSW method can be adapted for low-income countries taking into account the country’s specific resources and challenges. Some of the scenarios that are applied to low-income countries and remain effective are in the form of a thorough situational analysis of the country’s existing MSW waste management system, which includes existing policies, level of community participation, and waste management. Strategic planning focuses on plans for reduction, recycling, and safe and efficient management. In this case, it requires prioritizing steps with limited resources. Furthermore, a waste sorting and processing system is designed on the available resources. For example, create a simple recycling center to process waste that can be recycled. Even with limited resources, hazardous waste management is crucial to create a safe treatment facility to dispose of and recycle hazardous waste. Form partnerships with the private sector, nongovernmental organizations, and local communities for additional resources and technical support. This collaboration can significantly increase the effectiveness and sustainability of the IMSW system. Next, monitoring and evaluation can be carried out on areas needing improvement and necessary adjustments. Convincing countries to implement the recommended methods for sustainable MSW management does require effective effort and clarification. Education and information play a vital role in this regard. With clear and complete information on the benefits and advantages of the proposed techniques for sustainable MSW management, educate decision-makers and stakeholders about the environmental, economic, and social aspects of executing a sustainability plan. Assist the country/territory in strategic planning, regulatory support, and promotion of sustainable management of MSW. The government helps create supportive policies, proper legislation, and regulations for sustainable MSW management. To help the country adopt the proposed ways, form partnerships with governments, international agencies, NGOs, the commercial sector, and other sustainability-supporting sectors. In its application, an alternative analytical method is needed to assess the life cycle of the waste management system, such as Life Cycle Cost Analysis, which combines economic analysis and LCA to evaluate the costs of various sustainable waste management options. Life cycle energy analysis involves evaluating the energy consumption of the life cycle of a waste management system. *Social life cycle analysis* is an alternative that needs to be considered because this method considers people’s welfare, social inequality, employment opportunities, and public participation. IMSW allows for diminished environmental impact, increased resource efficiency, and enhanced waste management sustainability. A comparison of IMSW and a single technology from the citation literature yields very different results. Application of IMSW that is appropriate for each category of MSW waste, such as composting for organic waste, thermal methods for waste that is difficult to process and produces products such as electricity, integrated waste segregation that can still be used, development of landfills to convert into electricity, and collaborations by third parties, governments, and stakeholders are significant steps towards achieving the goal of "sustainable."

CONCLUSION

To provide methodological guidelines for carrying out an extensive LCA on MSW management systems, this review has looked at scholarly literature from all of the Asian nations that are currently available. The most effective approach according to each country's current and economic conditions has been identified using a rationalized technology/strategy ranking based on the evaluation results of many study categories. Based on the factors analyzed, implications and suggestions are given for the most suitable implementation in managing MSW based on the factors analyzed. The corresponding sections provide step-by-step descriptions of the LCA approaches examined in the research as well as comparisons of their differences. Meanwhile, this section briefly discusses several significant issues of establishing best practices for putting LCA for managing MSW into practice. Ensuring precise definitions and analysis goals—subjective and dependent on study goals—is a crucial stage in every LCA study. The study's scope comprises functional units, data selection, impact category selection, etc. Limitation differences are based on particular assumptions related to the goals of the studies. The study's depth is increased by the wider system boundaries and the variety of impact categories, but this also introduces uncertainty into the conclusions. To avoid bias, practitioners must be consistent in their evaluation of the scenarios to be examined. Sensitivity analysis is therefore required to determine the importance of the assumptions made about certain aspects in the study. Choosing one technology over another in the management of MSW is, therefore, something that needs to be studied, especially if this study's goal is to make decisions. Another important factor that needs to be further examined is the evaluation of the economic impact scenario because it affects state income. The analysis's concluding section chooses the optimum approach for managing MSW. The analysis findings revealed that a combination of IMSW management for recycling and resource generation (COMP, INC, AD), Collaboration and Partnership is the thing the author suggests in planning for sustainable MSW. Build partnerships with governments, international agencies, nongovernmental organizations, the private sector, and other sectors that support the concept of sustainability to support the country in implementing the suggested methods. Collaboration can involve exchanging knowledge and experience, technical assistance, training, and access to necessary financial or technological resources, intending to reduce the waste generation in landfills, which is necessary to achieve high environmentally friendly principles. This method is suggested as the most appropriate one to use in Asia. Costly technologies that demand highly qualified workers are only advised for high-income countries. In order to reduce the amount of waste sent to landfills, low-income countries should focus on waste reduction strategies such as recycling, waste banks, and approaches consistent with their current practices. Some of the scenarios that are applied to low-income countries and remain effective are in the form of a thorough situational analysis of the country's existing MSW waste management system, which includes existing policies, level of community participation, and waste management. Landfilling is the final resort for managing MSW, yet it is inescapably a part of the waste management hierarchy and cannot be eliminated from the system since it is the simplest way to manufacture garbage, even though it is not a form of new energy. The application of IMSW is very significant in the environmental impact assessment process of MSW waste management throughout its life cycle. From the various technologies, the scenarios and recommendations reviewed have significant benefits in the form of a more comprehensive identification of environmental impacts. Evidence-based decision-making from information obtained through environmental impact assessments enables more accurate and evidence-based decision-making in developing waste management policies and strategies. Development of sustainable solutions, data, and information obtained through assessments can be used to increase efficiency, minimize pollutant emissions, increase recycling and introduce more environmentally friendly processing technologies. This method's effectiveness is influenced by local, existing variables, a nation's socioeconomic condition, and other considerations. A technology or policy's environmental impact may be influenced by significant factors that are different from the impact criteria. Moreover, the social preferences of stakeholders, including shareholders, the government, and citizens, impact on how policies are implemented. Because of this, making the best option for a nation depends on considering the economic, social, and environmental effects made by decision-makers. The analysis results reveal important factors in selecting the LCA's field of applicability. Insights for creating sustainable MSW management systems are also provided, allowing LCA practitioners and stakeholders to influence public policy in Asia.

AUTHOR CONTRIBUTIONS

M.A. Budihardjo is responsible for making MSW waste management distribution maps in Asia, writing initial drafts, and preliminary research. I.B. Priyambada is responsible for finding out the outline of each manuscript analyzed in managing MSW, determining bibliographical searches, compiling concepts, reviewing all manuscripts. A. Chegenizadeh is responsible for finding out the outline of each manuscript analyzed in managing MSW, determining bibliographical searches, compiling concepts, reviewing all manuscripts. S. Al Qadar reviewed the final report. A.S. Puspita Puspita is responsible for preparing drafts, journal analysis sources and reviewing the entire manuscript.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

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PUBLISHER'S NOTE

ABBREVIATIONS

%	Per cent
AcRR	All component resources recovery
AD	Anaerobic digestion
ADP	Abiotic depletion potential
AL	Aerobic landfilling
AP	Acidification potential
ATT	Advance thermal treatment
BBR	Biogas and biodiesel recycling
BLF	Bioreactor landfill
CDS	Control disposal site
CLL	Collection
CO_2	Carbon dioxide
COMP	Composting

CROESB	Carbonthermal reduction oxygen enriched side blowing
DAR	Depletion of abiotic resources
DDFD	Directional deploymerization flocculatuon demulsification
DWR	Dry water recycling
Ecs	Ecotoxicity soil
ECT	Eco-toxicity
Ecwc	Ecotoxicity soil
EP	Eutrophication potential
Etwc	Ecotoxicity water chronic
FAETP	Freshwater aquatic ecotoxicity potential
FD	Fossil depletion
FE	Photochemical ozone synthesis
FEW	Freshwater aquatic ecotoxicity potential
FW	Food waste
GDP	Gross domestic product
GS	Gasification
GWP	Global Warming Potential
HIC	Higher income countries
HT	Human toxicity
Hta	Human Toxicity air
HTw	Human toxicity water
IMSW	Integrated solid waste management
INC	Incineration
IWMS	Integrated waste management system
KRS	Kerbside recycling system
LCA	Life cycle assessment
LCCA	Life cycle cost analysis
LFG	Landfill with gas
LIC	Low income countries
LMIC	Lower middle income countries
MAE	Marine aquatic ecotoxicity potential

MBCS	Material bank collection recycling system
MRF	Material recovery facility
MRS	Mineral resources scarcity
MSW	Municipal solid waste
Mt	Million ton
NE	Nutrient encrichment
NO_x	Nitrogen oxides
OF	Organic Fertilizer
OB	Open Burning
ODL	Open dumping landfill
ODP	Ozone depletion potential
OWM	Organic waste management
PC	Pre-composting
PMF	Particulate matter formation
POCP	Photochemical ozone creation potential
POF	Photochemical ozone formation
POS	Photochemical ozone synthesis
RCYCL	Recycle
RDF	Refused derived fuel
RWM	Residual waste management
SAL	Semi aerobic landfilling
SD	Scatted dumping
SF	Sintetic fertiliezer
SLF	Sanitary landfill
SO_2	Sulfure dioxide
SRT	Sorting
TET	Terrestrial eco-toxicity
t/y	Ton per year
UMIC	Upper middle income country
USD	United States dollars
VOC	Volatile organic compound
WD	Water depletion
WWTP	Waste water treatment plant

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