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Urban Solid Waste Management Systems: Sources, Characterisation and Technologies: A Review

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Keywords

Municipal Solid Waste;
Waste Characterisation;
Waste Technologies;
Informal Recycling;
Circular Economy;
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Abstract

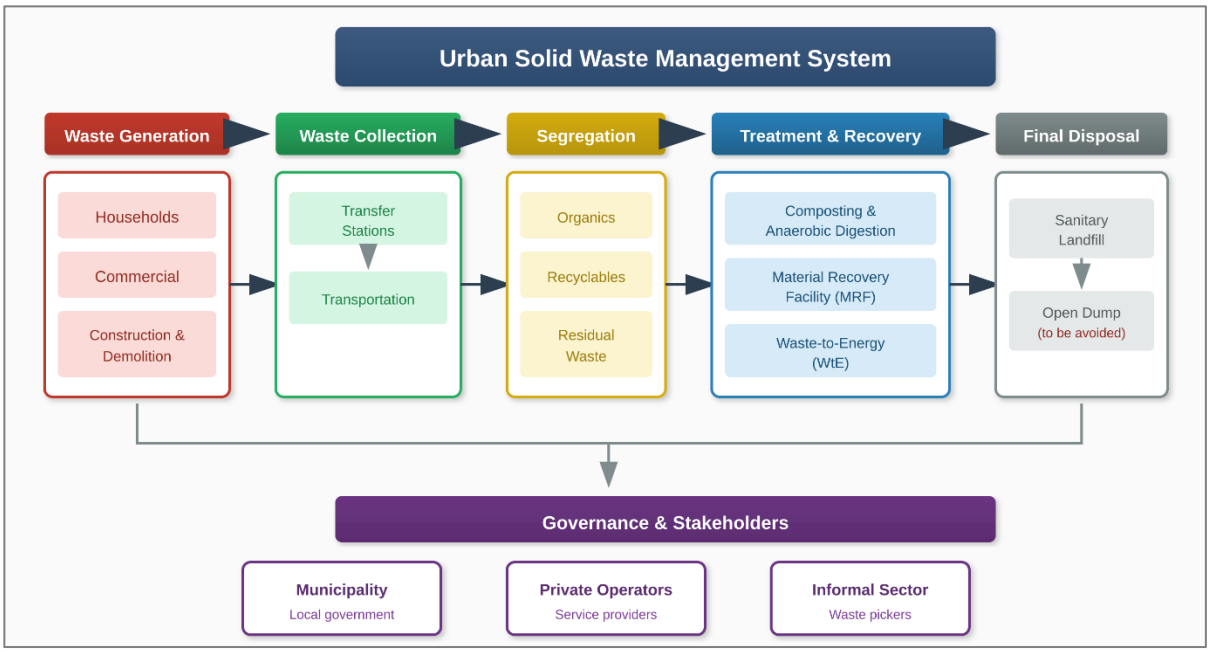
Generation of solid waste has increased with development and urbanisation, posing threats not only to the environment but also to the survival of human civilisation. This review paper synthesises the existing research carried out on solid waste management practices in urban areas, focusing on interlinked dimensions, viz. (a) sources and generation patterns of solid waste; (b) physico-chemical and biological characterisation of solid waste; (c) methods evolved for treatment, recovery, and disposal of solid waste; and (d) role of government, institutions and policy mechanisms linked with the solid waste. The main focus is on variation across regions, technology–context fit, resource recovery pathways and prospects for development of the circular economy. The review includes evidence from recent meta-analyses, technology reviews, and governance studies, emphasising important trade-offs and policy essentials for resilient, sustainable waste management systems in urban areas. The review paper concludes with suggestions for integrated monitoring, capacity building, and regulatory reforms to advance circular and safe waste systems in rapidly urbanising regions.

1. Introduction

Urban areas across the world face the challenges linked with an increasing amount and varying types of solid waste. Economic development, increasing urban population and shifts in consumption patterns have transformed both the volume and composition of urban wastes (Kaza *et al.,* 2018). Historically, many systems were designed for simple removal and disposal of solid waste in the interest of public health, but modern sustainable development goals require moving beyond disposal to resource recovery, mitigation of greenhouse gases and reduced environmental pollution (Wilson, 2006; Kirchherr *et al.,* 2017).Two framing points guide this review paper. First, management of solid waste in urban areas is best understood as a socio-technical system in which the physical flows of material, the technologies that process those flows, and the governance arrangements that enable or restrict action are strongly tied (Brown *et al.,* 2009). Second, context matters, concerning regional differences in waste composition, informal sector participation, infrastructure, and institutional capacity, which regulate viable technology choices and governance options (Wilson *et al.,* 2006). In a nutshell, there is no universal “best” solution. Hence, the

technology–policy packages must be custom-made, keeping in view the local realities while informed by global evidence.

Figure 1 shows the different stages of managing the MSW in urban areas. It shows the phases of waste generation from domestic, commercial, and construction sites to final disposal. The second step involves the collection and transportation of the MSW through transfer stations, followed by the third phase that involves its separation into bio-degradable, recyclable, and residual fractions. The next step is the treatment and recovery through various processes, like composting, anaerobic digestion, and material recovery facilities. The final disposal of MSW is done at sanitary landfills or open dumps. The figure also depicts the role of the government and the involvement of various stakeholders.



Note: Governance and stakeholders operate as cross-cutting elements influencing all stages of the waste management system. System performance depends on coordination among municipal authorities, private operators and informal sector actors.

Fig. 1: Conceptual context of urban solid waste management system

1.2. Theoretical Framework: The integrated socio-technical and governance framework adopted in this review is demonstrated in Figure 1. Besides this, this review paper is based on the following key concepts:

1.2.1. Solid Waste Management System in Urban Areas: This review paper is based on the knowledge that has evolved in the context of solid waste management in urban areas, which acts as a socio-technical system. This means that the flow of material, methods, institutions, and social actors is interconnected, and these interact to influence environmental outcomes. Socio-technical systems theory holds that services like waste management are not merely technical systems; they are also shaped by social norms, governance arrangements, economic incentives, and political power relations (Geels, 2004; Markard *et al.,* 2012). From this viewpoint, problems in waste management cannot be described merely by technological limitations. Instead, they often arise

from a lack of coordination between technical systems and social or institutional settings. When applied to the management of municipal waste in urban areas, this framework shows the link between waste generation patterns, collection and treatment methods, users' behaviour, such as waste segregation, and regulatory frameworks. For example, the success of composting or anaerobic digestion depends not only on the technology itself. It also depends on household participation in the segregation of waste at source and on the institutional efficiency in enacting the regulations. Generally, this socio-technical approach helps explain why many technically sound waste management solutions turn out to be unsuccessful in practice, mainly in rapidly urbanising areas.

1.2.2. Material Flow Theory: This paper also focuses on urban metabolism theory, which considers cities as systems of material and energy flows, comparable to biological organisms (Wolman, 1965; Kennedy *et al.,* 2007). Within this framework, solid waste is recognised as an important output of urban metabolism, indicating the consumption, production, and resource use patterns in the urban areas. Waste characterisation and treatment technologies can thus be regarded as mechanisms that redirect material flows away from linear "take–make–dispose" processes towards more circular pathways. Material Flow Analysis (MFA) represents an important methodological expansion of urban metabolism theory and supports much of the studies reviewed in this paper. MFA provides a quantitative basis for analysing waste generation, recycling rates, energy recovery potential, and environmental emissions. By situating solid waste management within the broader urban metabolic system, this framework helps in assessing the waste management approaches not only in terms of disposal efficiency but also regarding resource recovery, ecological sustainability, and system resilience.

1.2.3. Concept of Waste Management Hierarchy and Circular Economy: This review paper also uses and links the concept of waste management hierarchy and circular economy theory. According to this concept, the hierarchy places waste prevention as the topmost priority. Reuse, recycling, recovery and disposal are placed subsequently. The hierarchy is widely used in policy. However, it serves as a general direction and not a strict rule. Its use depends on the local context (Allwood *et al.,* 2011). According to Kirchherr *et al.* (2017), circular economy theory takes into account the closed material loops, eco-design, and extended producer responsibility. It helps in assessing urban waste methods and governance systems, highlighting demanding actions, such as product design, reducing packaging, and developing markets for secondary materials. In this framework, solid waste management is considered not just a municipal service of the urban governing body. It is a part of sustainable production and consumption systems. The paper uses this approach to examine whether policies and technologies support linear waste practices or enable circular change. Figure 2 shows the waste management pyramid, from prevention to disposal, including circular economy loops.

1.2.4. Integrated Conceptual Framework for the Review: This review uses an integrated conceptual framework that combines socio-technical systems theory, urban metabolism, and circular economy principles, viewed alongside the institutional and policy dimensions examined in Section 7. Within this framework, urban solid waste management is understood in three main ways. Firstly, it is a material flow system, which is shaped by consumption patterns and the types of waste generated. Secondly, it is a technological system that includes collection, treatment, recovery, and disposal infrastructure. Thirdly, it is a governance system that involves many actors, institutions, and policy tools working at different levels. This framework guides the structuring and analysis of the reviewed literature. It supports a broad understanding of how technical,

environmental, and institutional factors interact. Therefore, the review goes beyond simple description, thereby offering a more descriptive and policy-relevant analysis of key challenges and opportunities in the management of solid waste in urban areas.

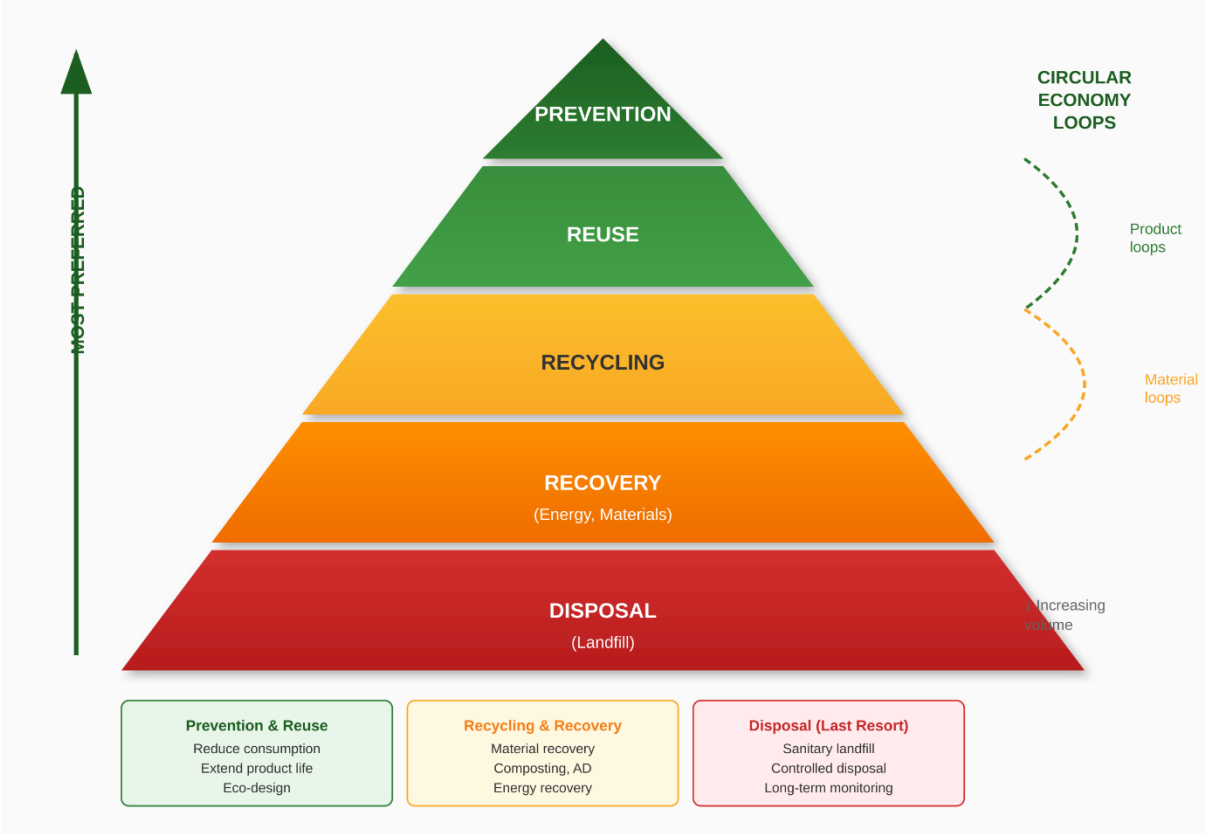


Fig 2. Waste management hierarchy and circular economy principles

2. Sources and Generation Patterns

2.1 Principal sources and sectoral contributions: Urban solid waste comes from diverse sources, including households and commercial activities, such as markets, restaurants, and shops. It also comes from institutions like schools and hospitals. Construction and demolition (C&D) activities are another major source. Catering and market waste and street sweeping by municipalities also add to waste streams. In most urban localities, households contribute to most of the daily municipal solid waste. However, according to many research studies, during periods of rapid construction, C&D waste has turned out to be the largest component (Hoornweg and Bhada-Tata, 2012; Kaza *et al.,* 2018). Healthcare facilities generate specific types of hazardous waste that need separate handling and are often subject to strict regulations.

2.2 Drivers of waste generation: With increasing income, the per-capita waste generation has also shown an increasing trend. It is also linked to urban lifestyles and consumption habits. High-income towns usually generate more packaging waste. This includes paper, plastics, and cardboard. Studies have shown that low- and middle-income town often produce more organic waste, including food and yard waste (Kaza *et al.,* 2018; Naveen *et al.,* 2018). Waste generation is also governed by the seasonal factors, such as harvest periods, festivals, and tourism, which affect both the amount and type of waste. Sudden events, such as natural disasters or market

closures, cause sharp changes, making waste collection and treatment planning more difficult (Singhal *et al.,* 2022). Table 1 summarises the main factors that influence waste generation patterns.

Table 1. Key drivers of urban solid waste generation

Driver Category	Specific Factors	Impact on Waste Generation
Socio-economic	Income level, urbanisation rate, lifestyle patterns	Higher income → more packaging, e-waste; Lower income → more organics
Demographic	Population density, household size, and age distribution	Higher density → concentrated generation; Smaller households → more per-capita waste
Consumption	E-commerce growth, single-use plastics, and food habits	Increased packaging, delivery materials, and food waste volumes
Seasonal	Festivals, harvest periods, tourism	Occasional spikes in organic waste, packaging, and mixed waste
Institutional	Schools, hospitals, and commercial establishments	Specialised waste streams requiring separate handling
Construction	Urban development, infrastructure projects	C&D waste dominates during construction surges

2.3 Informal sector and secondary resource flows: In many developing cities, the informal recycling sector plays a major role. This sector includes waste pickers, wandering buyers, and small-scale collectors. These actors recover large amounts of recyclable materials. Their work provides income and supports material recovery. However, most studies show that it also involves health risks and weak regulatory protection (Wilson *et al.,* 2006; Kala, 2022). When informal workers are included in formal recycling systems, diversion rates can improve. Researchers have shown that social protection can also increase if policies are designed with their participation (Wilson *et al.,* 2006; De Bercegol *et al.,* 2017).

3. Characterisation of Urban Solid Waste

3.1 Need for proper characterisation: Waste characterisation is considered vital for effective waste management planning because it supports the proper design of collection systems, transfer stations, treatment facilities, and monitoring processes (Burnley, 2007). When waste composition data are lacking or defective, technology choices are often inappropriate. For example, incinerators may be applied to waste with high moisture content, which reduces efficiency. Poor information can also increase environmental and operational risks.

3.2 Physical composition and calorific values: Studies from different regions show wide variation in waste composition. Organic waste typically ranges from about 20% to 70% by weight. Plastics usually account for around 5% to 25%, while paper ranges from 5% to 35% (Burnley, 2007; Ozcan, 2016). These shares vary across income groups. Calorific value increases with higher plastic and paper content. It is considered a key factor while assessing options for thermal treatment and energy recovery (Ramos *et al.,* 2023).

3.3 Chemical pollutants, hazardous fractions, and leachable constituents: Some waste streams contain hazardous materials. These include household hazardous waste such as paints, solvents, and batteries. E-waste and industrial residues are also important sources of hazardous fractions. These wastes often contain heavy metals and persistent organic pollutants. Studies have shown

that during disposal or treatment, these substances can enter leachate or remain in combustion residues, which creates environmental and health risks and requires special targeted management approaches (Slack *et al.,* 2005; Li *et al.,* 2021). Regular chemical testing is therefore necessary. Such analyses usually focus on heavy metals, persistent organic pollutants (POPs), and emerging contaminants such as pharmaceuticals. According to most scientific studies, this information is important for proper risk assessment and system design (Slack et al., 2005; Turner, 2018).

3.4 Biological and biodegradability metrics: Biological characteristics strongly influence treatment options. Key parameters include moisture content, volatile solids, carbon-to-nitrogen ratios, and biochemical oxygen demand (BOD/COD). These factors determine whether waste is suitable for composting or anaerobic digestion. Research studies have shown that they help in estimating methane generation in landfills (Christensen *et al.,* 2001; Chatterjee and Mazumder, 2016). In addition, studies of microbial communities provide useful information. They help assess waste stabilisation and pathogen reduction during composting and digestion. This is important when compost is reused (Sekhohola-Dlamini and Tekere, 2020).

4. Collection, Transfer, Segregation and Transportation

4.1 Collection systems and operational efficiency: Collection exhausts the largest share of municipal SWM budgets and is a main determinant of final system performance. Route optimisation, vehicle capacities, transfer station locations and frequency of collection directly impact service coverage, cost and illegal dumping (Wilson *et al.,* 2015).

4.2 Source segregation and its enabling measures: Source segregation into organics, recyclables and residuals considerably improves downstream processing options. Municipal programs, producer responsibility rules and community engagement have had mixed success; segregation rates increase where user incentives, door-to-door collection and infrastructure (separate bins) are well coordinated (Wilson et al., 2015; Zaman *et al.,* 2022).

4.3 Transfer stations and logistics for large cities: Transfer stations reduce transportation distances, mainly for landfill-bound waste, but need careful siting, odour controls and integration with collection scheduling to avoid secondary nuisances (De Souza *et al.,* 2018).

5. Treatment, Recovery and Disposal Technologies

This section discusses the major technology types, in the context of their technology-context fit, benefits and limitations.

5.1 Biological treatments: Composting and anaerobic digestion: Composting is fit for source-separated organics, produces soil amendment products and lowers landfills' methane potential; however, it needs segregation and pathogen management (Hargreaves *et al.,* 2008). Studies have shown that anaerobic digestion (AD) of organic fractions offers renewable energy (biogas) and stabilised digestate, but success depends on feedstock homogeneity, pre-treatment, and operational control (Chatterjee and Mazumder, 2016; Zamri et al., 2021).

5.2 Thermal processes: Incineration, gasification, pyrolysis, and waste-to-energy (WtE): Thermal technologies reduce waste volume and generate energy but require strict emissions control (dioxins, heavy metals) and are capital-intensive (Astrup *et al.,* 2015). The carbon and material trade-offs between WtE and high-rate recycling are an important policy consideration; life-cycle assessments often inform these trade-offs (Astrup *et al.,* 2015; Ceraso *et al.,* 2024).

5.3 Engineered sanitary landfills and controlled disposal: Well-designed landfills with liners, leachate collection and gas recovery remain an extensively used solution but need long-term management and monitoring to prevent groundwater contamination and fugitive emissions (El-Fadel *et al.,* 1997). Legacy, unlined landfills are common in many regions and present ongoing remedial challenges.

5.4 Material recovery and recycling infrastructure: Material recovery facilities (MRFs), mechanical-biological treatment (MBT), and specialised e-waste or battery recycling require investments in technology and market development for secondary materials. According to researchers, informal sector integration is often the most cost-effective near-term pathway for improved recovery in lower-income cities (Wilson *et al.,* 2006; Velis and Wilson, 2012).

Table 2. Major urban solid waste treatment technologies and key attributes

Technology	Suitable Waste Type	Key Benefits	Major Limitations
Composting	Organic waste	Nutrient recovery, soil amendment	Requires segregation
Anaerobic digestion	Wet organic waste	Biogas and energy recovery	Feedstock sensitive
Incineration / WtE	High calorific waste	Volume reduction, energy recovery	High cost, emissions
Sanitary landfill	Residual mixed waste	Controlled disposal	Long-term environmental risks

Table 2 compares the main waste treatment technologies. It focuses on key decision factors, like suitable waste types, benefits, and limitations. The comparison helps policymakers and planners choose suitable technologies and supports procurement decisions by linking technology options to local waste characteristics and institutional capacity.

6. Environmental Impacts, Health Risks and Monitoring

6.1 Leachate, groundwater and surface water contamination: Leachate contains organic matter, ammonia, chloride, and heavy metals. In unlined landfills and open dumps, leachate can easily seep into the ground. Studies have shown that it can contaminate groundwater and reach nearby surface water bodies (Kjeldsen *et al.,* 2002; Renou *et al.,* 2008). Regular monitoring of leachate quality is thus important. Groundwater monitoring is also needed to detect pollution early and support timely remediation.

6.2 Air emissions and greenhouse gas implications: Anaerobic decomposition in unmanaged landfills is a major methane source. Gas capture systems and anaerobic decomposition can lessen emissions and recover energy (IPCC methodologies). Thermal facilities need robust air pollution control systems to manage particulates, NOx, SOx and trace organics (Astrup *et al.,* 2015).

6.3 Occupational and public health concerns: Informal recyclers and waste workers face exposure to pathogens, hazardous chemicals and physical hazards. Studies recommend formalising and protecting workers, providing PPE and training, and improving on-site segregation reduce health risks (Yang, 2018; Kala, 2022).Table 3 links impact categories to monitoring parameters and mitigation measures for comprehensive environmental management.

7. Governance, Institutional Arrangements and Policy Instruments

7.1 Institutional models and financing: Municipal provision, public–private partnerships (PPP), franchising and decentralised community models all exist. Studies have shown that the performance of governance models depends on clear roles, financing mechanisms (user fees, earmarked taxes), capacity for enforcement and transparency (Brown *et al.,* 2009; OECD, 2020).

Table 3. Environmental and health impacts of waste management with monitoring parameters

Impact Category	Key Pollutants/Issues	Monitoring Parameters	Mitigation Measures
Groundwater Contamination	Leachate: organics, ammonia, heavy metals	BOD, COD, NH_3-N, heavy metals, pH	Liners, leachate collection and treatment
Surface Water Pollution	Runoff carrying waste-derived contaminants	TSS, nutrients, pathogens, toxicity	Buffer zones, constructed wetlands
Air Emissions	Landfill gas (CH_4, CO_2), incinerator emissions	CH_4, PM, NOx, SOx, dioxins/furans	Gas capture, emission control systems
Soil Contamination	Heavy metals, persistent organic pollutants	Soil heavy metals, PAHs, PCBs	Proper containment, remediation
Occupational Health	Pathogen exposure, chemical hazards, injuries	Worker health surveillance, accident rates	PPE, training, and mechanisation

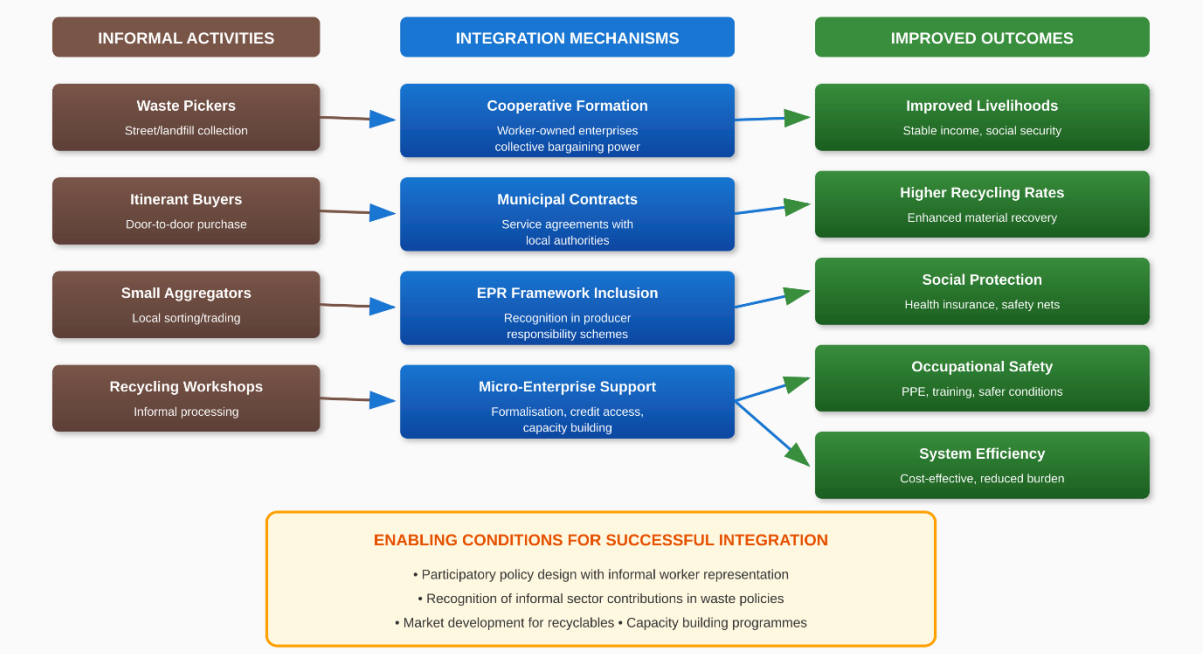
7.2 Regulatory instruments and economic incentives: Extended Producer Responsibility (EPR), landfill taxes, PAYT (pay-as-you-throw), and deposit-return schemes have shown effectiveness in changing material flows when designed and enforced properly (OECD, 2020; Kirchherr *et al.,* 2017). Table 4 compares the main governance models used in urban solid waste management. Each model involves different trade-offs. These trade-offs relate to public accountability, operational efficiency, and social inclusion. Municipal systems usually provide wide service coverage. However, they often face financial and capacity limits. Public–private partnerships can improve efficiency but require strong contract design and monitoring. Community-based and cooperative models focus more on social inclusion, but they are also helpful in integrating informal waste workers. The choice of governance model must depend on local institutional capacity, available financing, and social priorities.

Table 4. Comparison of governance models for urban solid waste management

Model	Characteristics	Advantages	Challenges
Municipal Provision	Direct public operation and management	Public accountability, universal coverage	Limited resources, political interference
Public-Private Partnership	Contractual arrangements with private operators	Efficiency gains, technology transfer	Contract complexity, profit motives vs public interest
Franchising	Area-based service contracts	Competition, specialisation	Coordination difficulties, service boundaries
Community-Based	Decentralised local management	Local ownership, flexibility	Capacity constraints, scalability limits
Cooperative Model	Worker-owned waste enterprises	Social inclusion, livelihood protection	Market access, capital limitations

7.3 Social inclusion and the informal sector: Many studies have focused on participatory plans that integrate informal recyclers, through cooperatives, micro-enterprises and formal contracts to improve diversion while protecting livelihoods (Wilson *et al.,* 2006; De Bercegol *et al.,* 2017). Figure 3 shows how informal waste workers can be integrated into formal waste management systems. It starts with existing informal activities. These include waste picking, itinerant buying, and small-scale aggregation. The framework then shows transition steps. These include

constituting cooperatives, providing training, improving access to finance, and recognising workers in policy. The final stage is formal integration. This includes municipal contracts, partnerships under extended producer responsibility (EPR), and work in material recovery facilities (MRFs). Successful integration brings several benefits, including more stable incomes, better health protection, higher recovery rates, and improved system efficiency. Key factors for success include participatory policy design, gradual transitions with adequate support, and long-term political commitment.



Adapted from Wilson et al. (2006), De Bercegol et al. (2017), and Kala (2022)

Fig 4. Pathways for integrating informal waste sector into formal systems

7.4 Digitalisation and data-driven planning: Digital tools are increasingly used in waste management in urban areas. While smart routing helps optimise collection routes, weighbridge data improves tracking of waste quantities. Digital platforms also allow citizens to report service issues. GIS-based planning supports better decision-making. Together, these tools improve efficiency and transparency. Recent interventions of the judiciary and municipal initiatives show increasing use of digital systems (Times of India reporting; Emara, 2024). Sensors and robots have enhanced and improved the waste segregation process by mechanising identification and segregation, improving efficiency, and decreasing contamination in recycling streams. Computer vision and AI-driven robotic systems can rapidly segregate metallic, plastic, and paper waste. AI enhances waste management through predictive channelling and smart bin monitoring. Identification, capacitive, inductive, ultrasonic, and gas sensors can help in classification, separation and management of waste (Dao *et al.,* 2025).

AI-powered robotic arms equipped with cameras and sensors scan, pick, and sort materials on conveyor belts faster and more accurately than manual labour. These robots can perform High-Volume Processing. By automating sorting, robots considerably reduce contamination in recyclables, increasing the value and recyclability of materials (Adeoye, 2025).

Computer Vision and Machine Learning (ML) can analyse image data to classify different waste types with high precision.AI analyses data using sensors to optimize the routing of waste collection vehicles, decreasing consumption of fuel besides operational costs.AI models can help in scrutinising data to estimate waste generation patterns, facilitating better resource management.AI improves waste logistics by foretelling when the containers will be full and optimizing, leading to effectual, demand-driven pick-up plans (Saha *et al.,* 2025).

8. Circular Economy Perspectives and Life-Cycle Assessment

Circular economy approaches focus on reducing waste at the source. They promote reuse, repair, remanufacturing, and recycling. Studies have revealed that life-cycle assessment (LCA) and life-cycle cost analysis help compare different waste management options. These tools assess environmental impacts and costs across the full life cycle (Kirchherr *et al.,* 2017; Ceraso *et al.,* 2024). Moving towards circular systems requires clear and coordinated policies, as well as producer involvement and functioning markets for secondary materials.

Table 5. Policy instruments for circular economy transition in waste management

Instrument Type	Examples	Mechanism	Effectiveness Conditions
Regulatory	Landfill bans, segregation mandates, and emission standards	Command and control; legal compliance requirements	Strong enforcement capacity, monitoring systems
Economic	Landfill taxes, PAYT schemes, and deposit-return	Price signals to change behaviour and material flows	Proper pricing, anti-dumping measures
Extended Producer Responsibility	EPR for packaging, e-waste, batteries	Shifts end-of-life costs to producers	Clear targets, producer registration, and enforcement
Information-Based	Eco-labelling, waste audits, public reporting	Transparency and awareness building	Consumer awareness, data accessibility
Voluntary	Industry agreements, certification schemes	Flexible, market-driven compliance	Industry commitment, reputational incentives

Figure 5 presents the circular economy framework for solid waste management in urban areas. It shows closed material loops from raw material extraction to production, consumption, and collection. Materials then return to the system through recycling, composting, anaerobic digestion, or energy recovery. Disposal remains only a small residual option. Key principles include reducing waste, keeping materials in use for longer, and restoring natural systems. Policy tools such as extended producer accountability schemes, landfill taxes, and recycled content standards play an important role in supporting the shift from linear to circular material flows.

Table 5 compiles the main policy instruments used to support circular economy transitions in waste management. Regulatory instruments set rules and compliance requirements. Economic instruments use prices and financial incentives to reduce waste and increase recycling. Extended Producer Responsibility shifts end-of-life costs to manufacturers. This encourages eco-design and supports collection systems. The success of these instruments depends on enforcement capacity, coordination between institutions, and market conditions. Using a mix of policy instruments is generally more effective than relying on a single approach.

9. Research Gaps and Future Directions

Certain key gaps remain in the contemporary research and practice. Firstly, municipalities lack standardised and analogous long-term data on waste composition (Burnley, 2007). Secondly, a few studies link waste flows with water, energy, and climate systems in a combined manner; for instance, Galán-Martín *et al.* (2021) analyse an integrated system that separates wastewater at the source and mixes black water with organic municipal solid waste to generate electricity and heat. It shows that this approach can reduce freshwater demand by 30 per cent, increase renewable energy, and lower greenhouse gas emissions by up to 45 per cent compared to conventional systems.

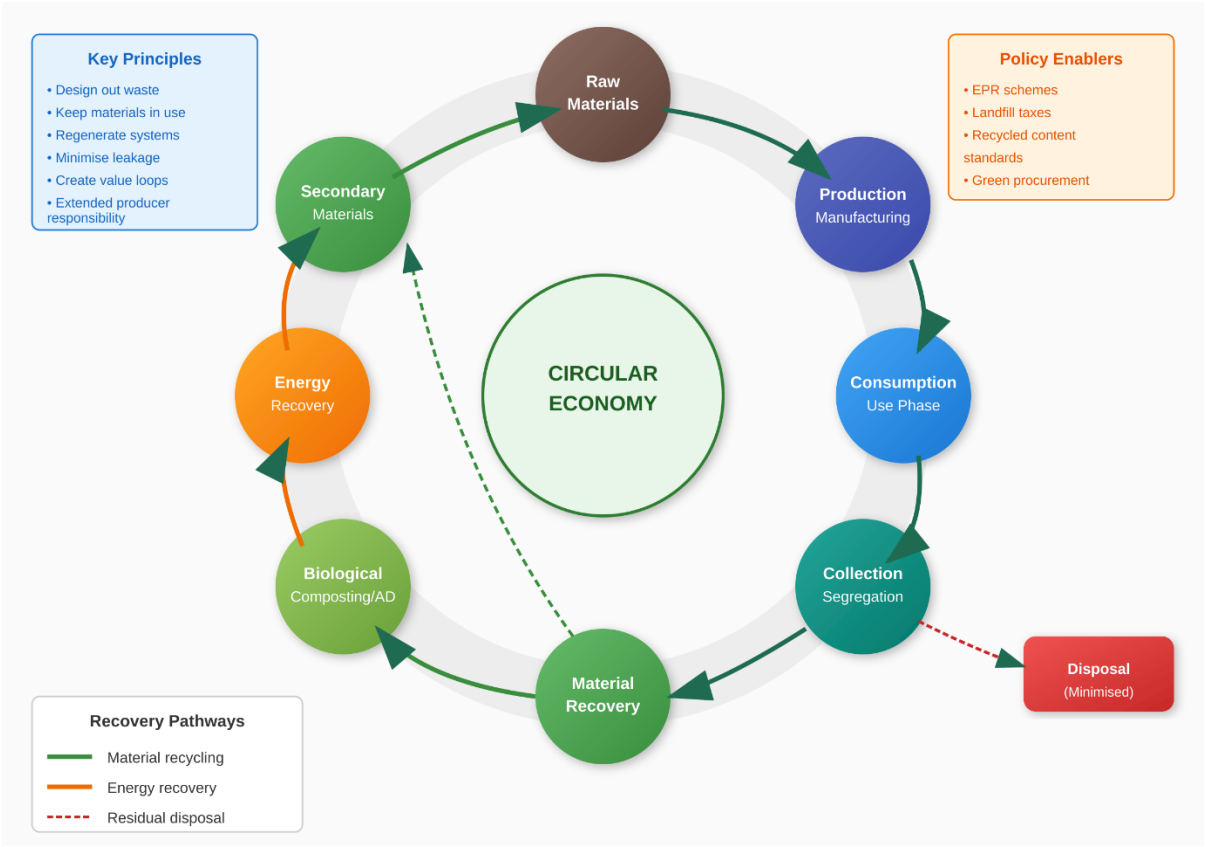


Fig 5. Circular economy framework for urban solid waste management

Thirdly, there is limited evidence on scalable models for integrating the informal waste sector. Fourthly, more rigorous life-cycle assessment studies are desirable. These must focus on socio-economic dimensions also, and not only on environmental impacts. Lastly, there is a lack of resilient design strategies for old landfills. This is significant under climate risks such as flooding and sea-level rise.

9.1 Research Gaps and Policy Priorities: In spite of progress in urban solid waste management, several gaps still limit the system's performance. A major challenge is the lack of reliable and long-term data on waste generation and composition. This problem is most acute in low- and middle-income nations. Many cities rely on one-time or obsolete waste studies, which do not take into account seasonal changes, income differences, or shifting consumption patterns. Subsequently,

planning is often weak. Hence, regular waste audits and formal data collection systems must therefore be a key policy priority. Policy frameworks must move beyond narrow, end-of-pipe methods. Urban waste systems are closely linked with water, energy, climate, and land-use systems. However, governance is often fragmented across departments. This leads to inadequacies such as landfill siting conflicts and poor leachate management. It also limits opportunities for energy and material recovery. Stronger synchronisation between agencies is required. Shared data platforms and integrated planning at metropolitan levels are particularly important. Another critical issue is the treatment of the informal waste sector. Informal recyclers play a key role in material recovery in many cities. Yet they often work without legal recognition, social protection, or safe conditions. Evidence shows that inclusive governance models can improve outcomes. These include cooperatives, municipal contracts, and EPR systems that involve informal workers. Such approaches can increase recycling rates while improving social equity. Policies must therefore focus on integration and capacity building rather than exclusion. Technology choices must also be context-specific. One-size-fits-all solutions often fail. In cities with high organic and moisture-rich waste, large thermal technologies have shown poor performance. They have also faced public resistance. In many cases, better results come from source segregation, decentralised composting or anaerobic digestion, and material recovery. Policy tools such as landfill taxes, pay-as-you-throw schemes, and incentives for decentralised treatment can support these choices.

Finally, beyond waste management, moving toward a circular economy needs action. Policies must address product design, packaging, and consumption patterns. Extended producer responsibility, eco-design rules, and recycled-content standards can reduce pressure on municipal systems. They can also support markets for secondary materials. Climate risks must also be considered. Extreme rainfall, flooding, and heat increasingly affect waste infrastructure. Integrating climate adaptation, life-cycle assessment, and sustainability indicators into waste policy is important to build resilient urban waste management systems.

10. Conclusion

Urban solid waste management has changed over time. It is no longer only a public health service. It is now a key part of sustainable urban development. This review shows that effective urban solid waste management cannot rely only on technology or disposal-based solutions. Instead, it needs an integrated approach that considers waste sources, waste composition, treatment and recovery options, and governance systems together as a socio-technical system. The review highlights big differences in waste generation and composition across places and suggests the need for local planning and regular waste characterisation. In many fast-growing cities, waste contains a high share of organic material. This creates opportunities for composting and anaerobic digestion. However, these options depend on source segregation and sufficient institutional capacity. Increasing amounts of waste create new environmental challenges, requiring flexible and responsive policies. Technology alone cannot deliver effective waste management. Governance conditions play a major role. Collection performance, treatment efficiency, and environmental effects depend on coordination between institutions, access to finance, execution of regulations, and stakeholder involvement. The informal waste sector is mainly important. Although often ignored, it adds substantially to recycling. When properly integrated, it can support circular economy goals. Future progress in management of solid waste in urban areas will depend on better alignment between technology and governance. It will also require reliable data systems and long-term policy planning. Circular economy principles, life-cycle assessment tools, and climate-sensitive planning offer useful pathways. These approaches can reduce environmental impacts and

improve resource recovery. By integrating evidence-based and socially inclusive strategies, cities can shift solid waste from a growing problem to a valuable resource, supporting public health, environmental protection, and sustainable urban development.

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References

Adeoye, S. 2025. Smart waste management systems: An IoT and AI-Driven approach for urban sanitation. *Computer and Information Science*; 18(2): 30–49. https://doi.org/10.5539/cis.v18n2p30

Allwood, J.M., Ashby, M.F., Gutowski, T.G., Worrell, E., 2011. Material efficiency: A white paper. *Resources, Conservation and Recycling* 55, 362–381. https://doi.org/10.1016/j.resconrec.2010.11.002

Astrup, T., Tonini, D., Turconi, R., Boldrin, A., 2015. Life cycle assessment of thermal waste-to-energy technologies. *Waste Management* 44, 52–63. https://doi.org/10.1016/j.wasman.2014.12.034

Barles, S., 2009. Urban metabolism of Paris and its region. *Journal of Industrial Ecology* 13, 898–913. https://doi.org/10.1111/j.1530-9290.2009.00169.x

Brown, R.R., Keath, N., Wong, T.H.F., 2009. Urban water management in cities: Historical, current and future regimes. *Water Science and Technology* 59, 847–855. https://doi.org/10.2166/wst.2009.029

Burnley, S.J., 2007. A review of municipal solid waste composition in the United Kingdom. *Waste Management* 27, 1274–1285. https://doi.org/10.1016/j.wasman.2006.06.018

Ceraso, A., Cesaro, A., 2024. Life cycle sustainability assessment of municipal solid waste management systems: A review. *Journal of Environmental Management* 368, 122143. https://doi.org/10.1016/j.jenvman.2024.122143

Chatterjee, B., Mazumder, D., 2016. Anaerobic digestion for the stabilisation of the organic fraction of municipal solid waste: A review. *Environmental Reviews* 24, 426–459. https://doi.org/10.1139/er-2015-0073

Christensen, T.H., Kjeldsen, P., Bjerg, P.L., Jensen, D.L., Christensen, J.B., Baun, A., Heron, G., 2001. Biogeochemistry of landfill leachate plumes. *Applied Geochemistry* 16, 659–718. https://doi.org/10.1016/S0883-2927(00)00082-2

De Bercegol, R., Gowda, S., Schindler, S., 2017. Municipal service and informal recycling sector interactions. *Resources* 6, 70. https://doi.org/10.3390/resources6040070

De Souza, R.G., Clímaco, J.C.N., Sant'Anna, A.P., Rocha, T.B., do Valle, R.A.B., Quelhas, O.L.G., 2018. Transfer station selection for sustainable solid waste management. *Sustainability* 10, 1197. https://doi.org/10.3390/su10041197

El-Fadel, M., Findikakis, A.N., Leckie, J.O., 1997. Environmental impacts of solid waste landfilling. *Journal of Environmental Management* 50, 1–25. https://doi.org/10.1006/jema.1995.0131

Emara, K., Daoud, A.O., William, M., Farag, M.A.M., 2024. An innovative approach to municipal solid waste characterisation for waste-to-energy processes in Egypt. *Cleaner Waste Systems* 9, 100161. https://doi.org/10.1016/j.clwas.2024.100161

Fletcher, T.D., Shuster, W., Hunt, W.F., Ashley, R., Butler, D., Arthur, S., Viklander, M., 2015. SUDS, LID, BMPs: The evolution and application of sustainable drainage in urban areas. *Water Research* 80, 89–100. https://doi.org/10.1016/j.watres.2015.04.030

Galán-Martín, Á., Vázquez, D., Cobo, S., Dowell, N.M., Caballero, J.A., Guillén-Gosálbez, G., 2021. Delaying carbon dioxide removal in the European Union puts climate targets at risk. *Nature Communications* 12(1), 1–12. https://doi.org/10.1038/s41467-021-26680-3

Geels, F.W., 2004. From sectoral systems of innovation to socio-technical systems. *Research Policy* 33, 897–920. https://doi.org/10.1016/j.respol.2004.01.015

Ghisellini, P., Cialani, C., Ulgiati, S., 2016. A review of the circular economy. *Journal of Cleaner Production* 114, 11–32. https://doi.org/10.1016/j.jclepro.2015.09.007

Hargreaves, J.C., Adl, M.S., Marrs, J., 2008. Composting municipal solid waste. *Waste Management* 28, 2349–2357. https://doi.org/10.1016/j.wasman.2007.09.003

Kala, K., Bolia, N.B., Sushil, 2022. Analysis of informal waste management. *Heliyon* 8, e09993. https://doi.org/10.1016/j.heliyon.2022.e09993

Kennedy, C., Cuddihy, J., Engel-Yan, J., 2007. The changing metabolism of cities. *Journal of Industrial Ecology* 11, 43–59. https://doi.org/10.1162/jie.2007.1107

Kirchherr, J., Reike, D., Hekkert, M., 2017. Conceptualising the circular economy. *Resources, Conservation and Recycling* 127, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Kjeldsen, P., Barlaz, M.A., Rooker, A.P., Baun, A., Ledin, A., Christensen, T.H., 2002. Present and long-term composition. *Critical Reviews in Environmental Science and Technology* 32, 297–336. https://doi.org/10.1080/10643380290813462

Li, W., Zhang, Y., Yang, M., Li, J., 2021. Heavy metal mobility. *Environmental Pollution* 268, 115847. https://doi.org/10.1016/j.envpol.2020.115847

Markard, J., Raven, R., Truffer, B., 2012. Sustainability transitions. *Research Policy* 41, 955–967. https://doi.org/10.1016/j.respol.2012.02.013

Naveen, B.P., Mahapatra, D.M., Sitharam, T.G., Sivapullaiah, P.V., Ramachandra, T.V., 2018. Characterisation of landfill leachate. *Journal of Environmental Management* 227, 206–214. https://doi.org/10.1016/j.jenvman.2018.08.072

Ozcan, H.K., 2016. Municipal solid waste characterisation. *Sustainability* 8, 1044. https://doi.org/10.3390/su8101044

Ramos, A., 2023. Waste characterisation and energy. *Detritus* 24, 3–12. https://doi.org/10.31025/2611-4135/2023.17262

Renou, S., Givaudan, J. G., Poulain, S., Dirassouyan, F., Moulin, P., 2008. Landfill leachate treatment. *Journal of Hazardous Materials* 150, 468–493. https://doi.org/10.1016/j.jhazmat.2007.09.077

Sekhohola-Dlamini, L.M., Tekere, M., 2020. Microbial ecology of landfills. *Waste Management* 102, 690–700. https://doi.org/10.1016/j.wasman.2019.11.037

Singhal, A., Dubey, B.K., Kumar, S., 2022. Seasonal characterisation. *Journal of Environmental Management* 320, 115803. https://doi.org/10.1016/j.jenvman.2022.115803

Slack, R.J., Gronow, J.R., Voulvoulis, N., 2005. Household hazardous waste. *Science of the Total Environment* 337, 119–137. https://doi.org/10.1016/j.scitotenv.2004.07.002

Turner, D.A., 2018. Emerging organic contaminants. *Waste Management* 78, 815–825. https://doi.org/10.1016/j.wasman.2018.05.050

Velis, C., Wilson, D., 2012. Informal recycling. *Waste Management & Research* 30, 889–894. https://doi.org/10.1177/0734242X12461771

Wilson, D.C., Rodic, L., Cowing, M.J., Velis, C.A., Whiteman, A.D., Scheinberg, A., Vilches, R., Masterson, D., Stretz, J., Oelz, B., 2015. Wasteaware indicators. *Waste Management* 35, 329–342. https://doi.org/10.1016/j.wasman.2014.10.006

Wilson, D.C., Velis, C.A., Cheeseman, C., 2006. Informal sector recycling. *Habitat International* 30, 797–808. https://doi.org/10.1016/j.habitatint.2005.09.005

Wolman, A., 1965. The metabolism of cities. *Scientific American* 213, 178–190. https://doi.org/10.1038/scientificamerican0965-178

Yang, H., Ma, M., Thompson, J.R., Flower, R.J., 2018. Waste management and public health. *Journal of Epidemiology and Community Health* 72, 237–243. https://doi.org/10.1136/jech-2016-208597

Zaman, A.U., Lehmann, S., Hossain, A., 2022. Circular economy pathways. *Journal of Cleaner Production* 331, 131842. https://doi.org/10.1016/j.jclepro.2021.130500

Zamri, M.F.M.A., Hasmady, S., Akhiar, A., Ideris, F., Shamsuddin, A.H., Mofijur, M., Fattah, I.R., Mahlia, T.M.I., 2021. Anaerobic digestion review. *Renewable and Sustainable Energy Reviews* 137, 110637. https://doi.org/10.1016/j.rser.2020.110637

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