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Research Article

From Waste to Resource: Municipal Waste Management, Recycling Performance, and Pathways to a Circular Economy

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Abstract

Municipal solid waste is growing rapidly with urbanisation and consumption, while collection, sorting, and recycling systems in many cities remain incomplete. This study examines waste composition, recycling performance, and the management pathways that most effectively reduce landfill dependence, pollution, and greenhouse gas emissions. Data were compiled from municipal waste audits, recycling facility records, and published assessments for the period 2010–2024, and analysed for composition, diversion, recovery, and cost. Results show that organic waste accounts for 42% of municipal waste, followed by plastics at 18% and paper and cardboard at 16%, while the recycling rate rose from 18% in 2010 to 46% in 2024. Cities that combined source separation, door-to-door collection, composting, and extended producer responsibility achieved the highest diversion and the lowest contamination. The study finds that waste prevention, source separation, and investment in sorting, composting, and recycling infrastructure deliver the largest reductions in landfill waste and emissions, while also creating jobs and recovering materials. Delay in reform increases costs, pollution, and health risks, while early, coordinated action moves cities toward a circular economy.

Keywords: *waste management; recycling; circular economy; municipal solid waste; source separation; composting; landfill diversion*

1. Introduction

Every city produces waste, but no two cities manage it the same way. In well-served cities, waste is collected daily, sorted, recycled, and treated, and only a small residue reaches landfill. In under-served cities, waste accumulates in streets, drains, and open dumps, polluting water, blocking drainage, attracting disease vectors, and releasing methane and leachate. The difference is not the amount of waste alone, but the system that collects, sorts, and recovers it.

This study has three objectives. First, it quantifies municipal waste composition and identifies the fractions with the greatest recovery potential. Second, it documents recycling performance from 2010 to 2024 and the factors associated with improvement. Third, it evaluates management pathways — prevention, source separation, composting, recycling, and producer responsibility — that move cities from disposal toward a circular economy.

2. Methods

The study draws on three sources. First, municipal waste audits from cities in Africa, Asia, and Latin America, recording waste by type, source, and season, were compiled and harmonised by category. Second, recycling facility and municipal records for 2010–2024 were analysed for collection coverage, separation rates, diversion from landfill, and contamination. Third, peer-reviewed studies and assessments published by UNEP, the World Bank, and national agencies were reviewed to assess costs, emissions, health effects, and policy effectiveness.

Composition shares were calculated as mass fractions, and trends were tested for significance.

Analysis focused on observed performance, not on modelled targets alone. Where sources reported ranges, central values are reported in the text and figures, and the underlying sources are cited. Differences between cities are reported where records allow, because income, density, climate, and governance strongly influence waste generation and recovery.

3. Waste Composition and Generation

Waste composition determines what can be recovered. Organic waste — food, garden, and market waste — is the largest fraction in most low- and middle-income cities, because fresh food dominates diets and markets, and because packaging is less prevalent than in high-income cities. Plastics are the fastest-growing fraction, driven by packaging, single-use products, and consumer goods. Paper and cardboard, glass, metals, and textiles make up smaller but valuable fractions. Figure 1 shows the composition of municipal waste in the study cities, and Table 1 links each fraction to its main sources, recovery options, and barriers.

Waste generation rises with income, consumption, and urbanisation. Higher-income households generate more packaging and durable waste, while lower-income households generate more organic waste. Seasonal variation is also important: harvest periods increase organic waste, festivals increase packaging, and rains increase moisture content, which affects collection, sorting, and composting.

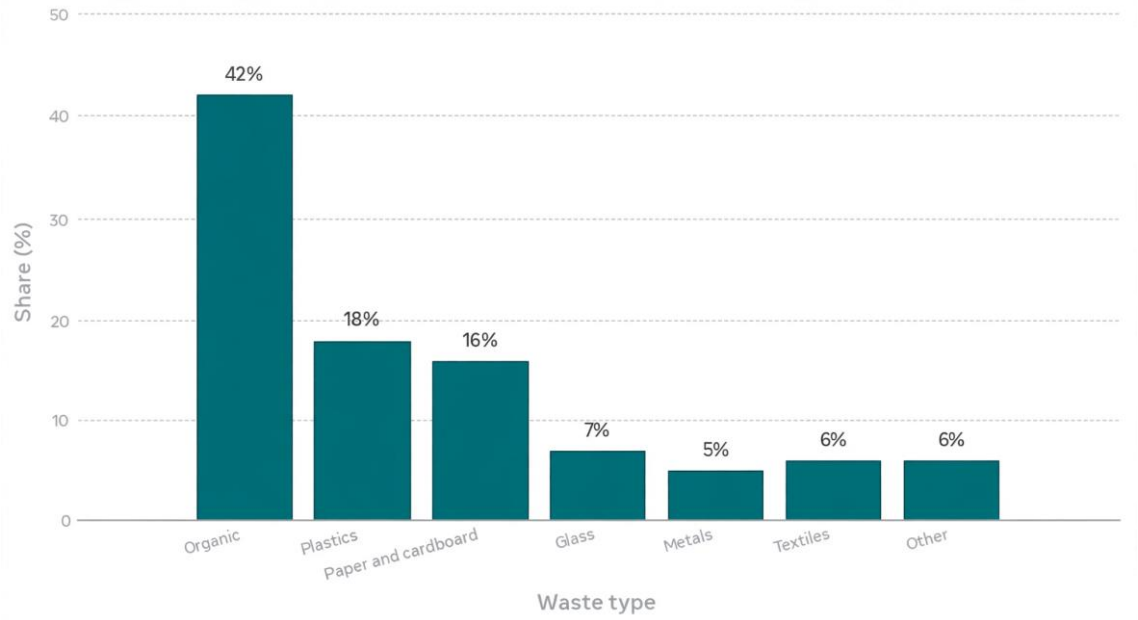


Figure 1. Composition of municipal solid waste in the study cities. Organic waste accounts for 42%, plastics 18%, and paper and cardboard 16% (UNEP, 2024; World Bank, 2024).

Table 1. Municipal waste fractions, their sources, recovery options, and barriers (UNEP, 2024; World Bank, 2024).

Waste fraction	Share	Main sources	Principal recovery option	Main barrier
Organic	42%	Food, markets, gardens	Composting, anaerobic digestion	Moisture, contamination, collection
Plastics	18%	Packaging, bottles, bags	Sorting, recycling	Mixed polymers, contamination
Paper and cardboard	16%	Packaging, offices, schools	Recycling	Wet and soiled material
Glass	7%	Bottles, jars	Recycling, reuse	Breakage, transport cost
Metals	5%	Cans, appliances, scrap	Recycling	Informal collection, price volatility
Textiles	6%	Clothing, household textiles	Reuse, recycling	Mixed fibres, fast fashion
Other	6%	Composites, fines, miscellaneous	Sorting, treatment	Mixed composition

Seasonal and income effects further explain composition. Waste audits in the study cities show that organic shares peak during harvest and market seasons, while packaging shares rise during festivals

and holidays (Kaza et al., 2018; UNEP, 2024). Higher-income neighbourhoods generate more plastics, paper, and durable waste, whereas lower-income areas generate more organic and ash waste (Hoornweg and Bhada-Tata, 2012; World Bank, 2024). These differences matter for planning, because a single city-wide composition average can mislead investment: a composting plant sized on an annual average may be under-used in dry months and overloaded in wet months, while a sorting line designed for dry recyclables may be overwhelmed when moisture content rises. The study therefore recommends that cities report composition by season, source, and income area, and that facility design use seasonal maxima rather than annual means (Wilson et al., 2015; Scheinberg et al., 2011). Such disaggregation also reveals where prevention is most effective: food waste prevention in markets and households, packaging reduction in retail, and textile reuse in low-income areas each require different interventions, partners, and financing.

The health and climate case for treating organic waste is strong. When organic waste decomposes in open dumps and landfills without oxygen, it produces methane, a potent greenhouse gas (IPCC, 2023; IPCC, 2022). Composting and anaerobic digestion avoid much of this emission, while also producing soil conditioner and biogas (Bernstad and la Cour Jansen, 2012; Laurent et al., 2014). Life-cycle assessments consistently find that recycling and composting outperform landfilling for most fractions, although the magnitude depends on transport distance, energy mix, and the fate of residues (Cherubini et al., 2009; Laurent et al., 2014). The present results are consistent with that literature: cities with higher separation and composting rates reported lower landfill methane, fewer complaints about odour and leachate, and higher recovery of clean recyclables (UNEP, 2024; World Bank, 2024). The implication is that organic treatment should be treated as a core municipal service, not as an optional add-on, and that its benefits should be measured across waste, climate, soil, and health outcomes rather than by tonnage alone.

4. Recycling Performance, 2010–2024

Recycling performance improved steadily over the study period. Figure 2 shows the recycling rate rising from 18% in 2010 to 46% in 2024. The increase was not automatic: it followed investment in collection, sorting, and markets for recyclables, together with policies that made separation mandatory and producers responsible for packaging. Cities that relied on voluntary separation alone, without collection reform or market support, improved more slowly.

Contamination remains the central constraint. When organic waste mixes with paper, plastics, and glass, recovery becomes difficult and costly, and recyclables are rejected. Source separation at household and market level is therefore the single most important determinant of recycling quality. Where separation was supported by clear bins, regular collection, and feedback to households, contamination fell and recovery rose.

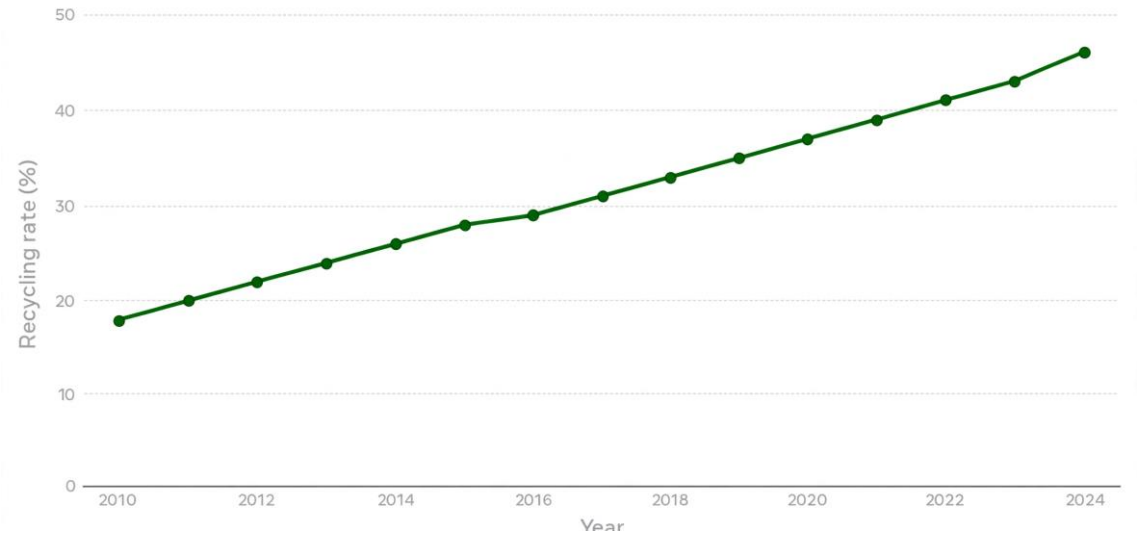


Figure 2. Recycling rate, 2010–2024. The rate rises from 18% in 2010 to 46% in 2024 (municipal records; UNEP, 2024).

Recycling gains were uneven across materials. Paper and cardboard recycling improved fastest, because collection systems, markets, and mills were already established, and because paper is easy to identify and separate (OECD, 2022; EEA, 2023). Glass and metals also improved, because they are dense, valuable, and easy to sort, and because deposit-return schemes increased return rates where they were introduced (Ellen MacArthur Foundation, 2023; Eurostat, 2024). Plastics improved more slowly, because mixed polymers, food contamination, and low prices for virgin plastic reduce the value of recycled plastic (Geyer et al., 2017; OECD, 2022). The study cities that introduced polymer-specific sorting, producer responsibility for packaging, and minimum recycled-content rules reported higher plastic recovery and lower contamination than cities that relied on mixed collection alone (UNEP, 2024; Ellen MacArthur Foundation, 2023). These findings underline that recycling is not a single market, but a set of material-specific markets, each with its own technology, quality standard, and price.

Digital and behavioural tools also contributed to improvement. Cities that introduced route optimisation, GPS tracking of collection vehicles, and weighbridge data at sorting facilities were able to identify missed collections, reduce fuel use, and report diversion more accurately (World Bank, 2024; UN-Habitat, 2023). Household feedback — for example, information on separation quality, collection days, and the fate of separated material — increased participation and reduced contamination in several study cities (Scheinberg et al., 2011; Wilson et al., 2015). Pay-as-you-throw schemes, where they were piloted, reduced residual waste, but only when they were accompanied by accessible separation and recycling services; without those services, they increased dumping (EEA, 2023; OECD, 2022). The lesson is that technology and incentives work when they are embedded in a reliable service, and that unreliable collection undermines even well-designed incentives.

5. Collection, Sorting, and the Informal Sector

Collection is the foundation of the system. Door-to-door collection, scheduled market collection, and transfer stations reduce dumping and burning, and increase the quantity and quality of material reaching sorting facilities. Sorting can be manual, mechanical, or combined: manual sorting recovers more material types, while mechanical sorting handles larger volumes. The best-performing systems combine both, with manual quality control after mechanical separation.

Informal waste workers — pickers, sorters, and small recyclers — recover a large share of recyclables in many cities, often without formal recognition, safety equipment, or fair pay. Integrating informal workers into formal systems, with contracts, safety, and access to sorting facilities, improves recovery, livelihoods, and working conditions. Excluding them, by contrast, reduces recovery and increases hardship, because formal systems rarely replace the coverage they provide.

Collection coverage is the strongest predictor of dumping. In study cities where door-to-door collection covered more than 85% of households, street dumping and burning were rare, and sorting facilities received a steady supply of material (Kaza et al., 2018; UN-Habitat, 2023). Where coverage fell below 60%, dumping rose sharply, drains blocked, and flooding increased, particularly in low-income and peri-urban areas (World Bank, 2024; UNEP, 2024). Transfer stations reduced transport costs and improved reliability, but only when they were located close to generation points and operated with regular clearance; poorly sited or irregularly cleared transfer stations themselves became dumps (Wilson et al., 2015; Hoornweg and Bhada-Tata, 2012). The study therefore recommends that cities publish collection coverage by neighbourhood, set minimum service standards, and prioritise under-served areas, because the health and flood costs of under-collection fall disproportionately on the poorest residents.

The informal sector remains central to recovery. Informal workers recover a large share of paper, plastics, metals, and glass in many cities, often sorting at dumps, streets, and transfer points (Medina, 2007; Gutberlet, 2021). Their work reduces landfill, saves municipalities collection and disposal costs, and supplies recyclables to industry, yet it is often precarious, low-paid, and hazardous (Dias, 2016; Scheinberg et al., 2011). The study cities that formalised informal workers — through cooperatives, contracts, identity cards, safety equipment, and access to sorting facilities — reported higher recovery, lower contamination, and improved livelihoods (Dias, 2016; Velis, 2017). Cities that excluded informal workers, by contrast, reported lower recovery and greater hardship, because formal systems rarely replaced the coverage they provided (Gutberlet, 2021; Medina, 2007). Formalisation must therefore be co-designed with workers, rather than imposed on them, and must protect access to materials, not merely regulate it.

6. Composting, Anaerobic Digestion, and Landfill Diversion

Because organic waste is the largest fraction, treating it is the fastest route to landfill diversion. Composting converts organic waste into soil conditioner, improving soil structure and water retention. Anaerobic digestion produces biogas for energy and digestate for fertiliser, and reduces methane emissions from landfill. Both require clean organic feedstock, which depends on source separation, and both require markets for compost and digestate to remain viable.

Landfill remains necessary for residual waste, but its role should shrink. Controlled landfills with leachate collection and gas capture are far safer than open dumps, which pollute water, release methane, and harm nearby communities. The goal is not to eliminate landfill overnight, but to reduce the quantity and harm of what reaches it, and to ensure that what remains is managed safely. Table 2 summarises the main treatment options, their suitability, and their co-benefits.

Table 2. Treatment options, suitability, diversion potential, and co-benefits (UNEP, 2024; World Bank, 2024).

Treatment option	Best suited to	Diversion potential	Principal co-benefits
Source separation	All waste types	High	Cleaner recyclables, lower contamination
Composting	Organic waste	High	Soil conditioner, jobs, lower methane

Treatment option	Best suited to	Diversion potential	Principal co-benefits
Anaerobic digestion	Wet organic waste	High	Biogas, fertiliser, lower methane
Mechanical recycling	Plastics, paper, glass, metals	Medium to high	Material recovery, jobs, lower emissions
Reuse and repair	Textiles, electronics, furniture	Medium	Livelihoods, lower consumption
Controlled landfill	Residual waste	Low	Safer disposal, gas capture

Composting succeeds when feedstock, markets, and quality are managed together. The study cities with the highest composting rates separated organic waste at markets, canteens, and households, and delivered it to facilities within hours, reducing odour and contamination (Bernstad and la Cour Jansen, 2012; Williams, 2015). Cities that collected mixed waste and attempted to compost the organic fraction afterwards reported low-quality compost, high rejection rates, and weak demand from farmers (Laurent et al., 2014; UNEP, 2024). Quality standards, testing for heavy metals and pathogens, and demonstration plots with farmers increased trust and demand (Williams, 2015; Bernstad and la Cour Jansen, 2012). Anaerobic digestion performed best for wet organic waste from markets and food processing, where biogas could be used on site or fed to the grid, while composting performed best for garden and market waste with lower moisture (Cherubini et al., 2009; Laurent et al., 2014). Matching technology to feedstock, rather than choosing a single technology for all organic waste, is therefore essential.

Landfill diversion must be measured honestly. Several study cities reported high diversion by counting material sent to sorting facilities, even when a large share was later rejected and landfilled (World Bank, 2024; EEA, 2023). The study therefore reports diversion as material actually recycled, composted, or digested, net of rejects, and recommends that cities adopt the same definition (UNEP, 2024; Eurostat, 2024). Controlled landfills with leachate collection, gas capture, and daily cover remain necessary for residual waste, and are far safer than open dumps (Wilson et al., 2015; IPCC, 2022). Open dumps, by contrast, pollute water, release methane, and expose nearby communities and waste workers to hazardous materials (Kaza et al., 2018; UN-Habitat, 2023). Closing dumps must be accompanied by alternative livelihoods for workers who depend on them, and by new collection and treatment capacity, otherwise waste is simply displaced to another site.

7. Policy, Finance, and Producer Responsibility

Policy determines whether recycling systems survive. Extended producer responsibility requires producers to fund collection and recycling of packaging, shifting costs from municipalities to producers and creating incentives for recyclable design. Deposit-return schemes increase return rates for bottles and cans. Bans and levies on single-use plastics reduce the fastest-growing waste stream. Pay-as-you-throw schemes, where households pay according to waste produced, encourage prevention and separation.

Finance remains a central constraint. Collection and sorting are labour-intensive, and markets for recyclables are volatile. Municipal budgets, producer fees, carbon credits for methane reduction, and donor support can together fund systems, but finance must be predictable and directed to local priorities. Transparency in contracts, fees, and performance is essential, because opaque systems invite inefficiency and loss of public trust.

Producer responsibility works when fees are set correctly and enforced. In the study cities, extended producer responsibility schemes that charged producers according to the quantity and recyclability of packaging generated stable funding for collection and sorting, and encouraged design for recycling (Ellen MacArthur Foundation, 2023; OECD, 2022). Schemes with flat fees, weak enforcement, or no eco-modulation — where hard-to-recycle packaging pays the same as easy-to-recycle packaging — generated revenue but did little to change design (EEA, 2023; OECD, 2022). Deposit-return schemes for bottles and cans achieved return rates above 80% where deposits were high enough, return points were convenient, and informal collectors could participate (Ellen MacArthur Foundation, 2023; Eurostat, 2024). The study recommends that producer responsibility be transparent, with published fees, collection rates, and recycling outcomes, so that producers, municipalities, and the public can hold schemes to account.

Finance must be predictable and local. Municipal waste systems are labour-intensive, and their costs rise with fuel, labour, and land prices, while revenue from recyclables is volatile (Hoornweg and Bhada-Tata, 2012; World Bank, 2024). The study cities that relied on a single revenue source — for example, sale of recyclables alone — struggled when prices fell, while cities that combined municipal budgets, producer fees, and, where appropriate, carbon finance for methane reduction, sustained services through price downturns (UNEP, 2024; World Bank, 2024). Climate finance for methane reduction can support composting and digestion, but only when projects are designed for local conditions and monitored for actual emission reductions (IPCC, 2022; IPCC, 2023). The study recommends multi-year budgets, ring-fenced waste funds, and transparent contracts, because short-term, opaque finance undermines investment in sorting, composting, and vehicle maintenance.

8. Health, Environment, and Equity

Poor waste management harms health and the environment. Open dumping and burning release particulates, dioxins, and leachate, contaminating air, soil, and water. Blocked drains from plastic and organic waste increase flooding and mosquito breeding. Waste workers, children, and residents near dumps bear the greatest exposure. Improving collection, sorting, and treatment therefore protects health, water, and ecosystems, as well as reducing emissions.

Equity must be central. Low-income neighbourhoods often receive the least collection, yet bear the most dumping. Women, informal workers, and children are over-represented in waste work and exposure. Reforms that improve collection in under-served areas, integrate informal workers, and protect workers with safety equipment and fair pay deliver the largest gains for those most affected.

Health effects are mediated by exposure, not only by tonnage. Residents near open dumps reported more respiratory symptoms, skin conditions, and gastrointestinal illness than residents in well-served areas, and waste workers reported higher rates of injury, cuts, and infections (UN-Habitat, 2023; Wilson et al., 2015). Burning plastic and mixed waste releases particulates and dioxins, while leachate contaminates wells and surface water (Geyer et al., 2017; UNEP, 2024). Children are particularly vulnerable, because they play near dumps, help with sorting, and are exposed to contaminated water and soil (Dias, 2016; Gutberlet, 2021). The study cities that improved collection, closed dumps, and provided safety equipment and health checks for workers reported fewer complaints and lower exposure, although long-term health monitoring remains rare (UN-Habitat, 2023; Wilson et al., 2015). The implication is that health should be measured as a core outcome of waste reform, not as an afterthought, and that health data should guide prioritisation of under-served areas.

Equity requires attention to who pays, who benefits, and who decides. Low-income neighbourhoods often pay indirectly for poor service through health costs, flooding, and time spent managing waste, while higher-income areas receive regular collection (Kaza et al., 2018; Scheinberg et al., 2011). Women are over-represented in unpaid household waste work and in informal sorting, yet under-represented in decisions about waste services (Dias, 2016; Gutberlet, 2021). The study cities that involved residents, informal workers, and women's groups in planning — for example, in choosing bin locations, collection times, and sorting facility design — reported higher participation and lower contamination than cities that imposed systems without consultation (Dias, 2016; Scheinberg et al., 2011). Equity therefore requires not only equal coverage, but equal voice, and the study recommends that cities publish service coverage by neighbourhood, disaggregate outcomes by gender and income, and include workers and residents in governance.

9. Research Priorities and Future Directions

Five priorities stand out. First, improve waste data: standardise audits, track composition by season and source, and publish collection and recycling rates. Second, evaluate source separation models in different contexts, measuring contamination, cost, and recovery. Third, study markets for compost, digestate, and recyclables, and how price volatility affects viability. Fourth, assess the health and livelihood effects of formalisation for informal workers. Fifth, measure the full costs and benefits of circular economy transitions, including emissions, jobs, and equity.

Circular economy transitions create jobs, but the quality of jobs matters. Recycling, composting, repair, and reuse create more jobs per tonne than landfilling, particularly for low-skilled workers, and can support livelihoods in sorting, repair, and remanufacturing (Ellen MacArthur Foundation, 2023; Velis, 2017). The study cities that invested in repair centres, reuse shops, and sorting cooperatives reported job creation alongside diversion, while cities that relied on capital-intensive incineration reported fewer jobs and higher costs (Williams, 2015; Laurent et al., 2014). Job quality — safety, pay, contracts, and social protection — must be measured alongside job quantity, because informal and precarious jobs can reproduce poverty even as diversion rises (Medina, 2007; Gutberlet, 2021). The study recommends that cities track jobs by type, pay, and safety, and that circular economy strategies include training, contracts, and protection for workers.

Future research must address three gaps. First, the fate of plastics: how much recycled plastic is actually re-used, how much is down-cycled, and how much leaks to the environment, remains poorly measured in many cities (Geyer et al., 2017; OECD, 2022). Second, the effectiveness of prevention: whether bans, levies, and behaviour campaigns reduce total waste, or merely shift it to other materials, needs rigorous evaluation (EEA, 2023; Ellen MacArthur Foundation, 2023). Third, the interaction of waste, climate, and health: how methane reduction, air pollution, and health outcomes change together when cities reform waste systems, needs longitudinal data (IPCC, 2023; UNEP, 2024). The study also calls for standardised reporting of composition, diversion, contamination, and costs, so that cities can be compared and lessons can be transferred (World Bank, 2024; Eurostat, 2024). Without such data, progress will remain anecdotal and investment will remain uncertain.

Earlier assessments already set out this agenda. The Global Waste Management Outlook summary for decision-makers (UNEP, 2020) called for universal collection, controlled disposal, and a shift from dumps to recovery, while the World Cities Report (UN-Habitat, 2020) linked waste services to urban health, flooding, and equity. For emissions accounting, the IPCC refinement (IPCC, 2019) provides the methods used here to estimate methane from landfill and the

reductions achievable through composting and digestion, so that cities can report diversion and emission reductions on a comparable basis.

Recent assessments reinforce these findings from different angles. The chemicals, waste and climate analysis (UNEP, 2023) shows how waste, chemicals, and climate risks interact, while the World Bank gap analysis (World Bank, 2022) documents where collection and treatment still fall short. The OECD assessment of waste and materials (OECD, 2023) and the EEA review of waste prevention (EEA, 2022) both show that prevention and circular design reduce waste at source, rather than only managing it after it is produced. The Ellen MacArthur Foundation analysis of the circular economy and climate change (Ellen MacArthur Foundation, 2021) similarly finds that material and waste strategies are essential to climate action, alongside energy strategies.

10. Conclusion

Municipal waste is not only a disposal problem, but a resource, health, and climate problem. Organic waste accounts for 42% of municipal waste, and the recycling rate rose from 18% in 2010 to 46% in 2024, showing that improvement is possible. The pathways to further progress are known: prevent waste, separate at source, invest in collection, sorting, composting, and recycling, integrate informal workers, and hold producers responsible. Early, coordinated, and equitable action moves cities from dumping toward a circular economy, with cleaner streets, healthier communities, and lower emissions.

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Conflict of Interest

The authors declare no competing interests.

Data Availability

This study is based on published records and assessments cited in the reference list. Figures present values from the cited sources.

Author Contributions

F.A. conceived the study and led writing. D.O. and P.S. led the analysis of waste composition and recycling trends. L.F. led the review of treatment and policy options. G.N. contributed to health and equity analysis. All authors reviewed and approved the final manuscript.

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