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Municipal Waste Composition and Its Implications for Source-Separation Planning in Selected Cities

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Abstract

Municipal waste composition provides an essential basis for source-separation planning, but its usefulness depends on the boundary of measurement and the conditions under which materials can actually be collected and recovered. This article develops a critical comparative synthesis of published evidence for Accra, Dhaka, and New York City, with Milan used as a supporting implementation example. It draws exclusively on literature published before 1 December 2024 and distinguishes original measurements from subsequent interpretation. The selected studies describe different populations, collection streams, dates, and material categories; their percentages therefore support conditional planning judgments rather than a statistical ranking of cities. The analysis connects composition to service coverage, material capture, contamination, treatment acceptance, institutional responsibilities, and distributional effects. Its contribution is a comparative decision framework that connects heterogeneous composition evidence to explicit collection and treatment assumptions, distinguishing material present from material captured and accepted into a specified process. An explicitly hypothetical calculation demonstrates why a large organic fraction can yield less usable material than a smaller fraction served by a more effective collection system. The article proposes differentiated collection arrangements, measurement at several points in the service chain, and staged investment tied to demonstrated performance. Composition remains indispensable, yet its planning value emerges through its combination with evidence about buildings, collection reliability, existing recovery practices, and downstream demand. Source separation should consequently be designed as a material-specific public service whose performance is assessed through accepted target throughput, documented product destinations, and equitable access, alongside waste prevention.

Keywords: municipal solid waste; waste characterization; source separation; organic waste; comparative urban analysis; collection planning

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Introduction

Municipal waste composition is consequential because every collection system makes assumptions about the materials that residents and businesses discard. Containers, collection frequencies, sorting equipment, and treatment facilities all embody expectations about quantities and qualities. A composition survey can make those expectations explicit, although a table of material percentages does not establish how much material households will separate or a processor will accept. The planning problem examined here is the translation between these two kinds of information. The article argues that composition should initiate a chain of decisions linking a defined waste stream to a feasible collection arrangement and a specified recovery destination. This approach gives composition data a stronger operational role while preventing the overinterpretation of measurements that were never designed to predict program performance.

International assessments provide a useful explanation of why cities need this translation. Kaza et al. (2018) document substantial variation in waste generation, material composition, collection, and treatment across income groups and urban contexts. Such broad patterns help identify plausible priorities, but assigning a national or regional average to a particular city can conceal differences in consumption, service coverage, and measurement practice. A municipal intervention must ultimately address the material encountered at particular premises and collection points. Global evidence therefore establishes context and a set of questions, while local measurements determine which assumptions are defensible. This distinction also prevents the common mistake of treating an organic fraction associated with an income category as a design specification for every municipality within it.

Waste management also has objectives that are poorly represented by a mass percentage alone. The Global Waste Management Outlook 2024 frames waste prevention and improved municipal services in relation to environmental, health, and economic consequences (United Nations Environment Programme [UNEP], 2024b). Nevertheless, a city can improve a reported diversion percentage while leaving some residents without dependable collection or transferring contaminated material to an unsuitable destination. The relevant outcome must consequently include the quality and destination of recovered material, the reliability of the service, and access to it. This article treats material recovery as one public-service objective within that wider evaluation, rather than assuming that the heaviest separated fraction necessarily produces the greatest overall benefit.

The comparison addresses three related questions. What aspects of published composition measurements can legitimately inform source-separation decisions across cities? How should differences in materials, sampling boundaries, and existing recovery arrangements alter the design of collection streams? What additional evidence is required before composition estimates can justify investment in facilities and service expansion? These questions cannot be answered through a pooled average of incompatible studies, and this article does not attempt such an estimate. Instead, it compares the decisions that different forms of evidence permit. The resulting contribution is a conditional planning framework: measured composition identifies an opportunity; evidence about accessibility, capture, quality, and destination determines whether that opportunity can become a dependable material flow.

Accra, Dhaka, and New York City offer informative contrasts because the available studies describe household discards, waste from several source types, and a documented residential collection system, respectively. Their inclusion is based on identifiable primary evidence with reported composition categories, rather than an assumption that they represent all cities in their regions. This purposive selection limits geographical generalization and rules out an inference that economic development alone explains their observed differences. It nevertheless permits close examination of a recurring planning error: moving from a percentage measured within one boundary to a conclusion about a different population or service. Milan supplies a narrower implementation comparison, illustrating questions about food-waste collection without being treated as a fourth equivalent composition dataset.

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Study Design and Evidence Appraisal

This study is a critical, purposive comparative review of published evidence, coupled with an original planning synthesis. Targeted web searches, conducted with a publication cutoff of 30 November 2024, combined city names with waste composition, waste characterization, source separation, capture, contamination, and household recycling. Original study tables and municipal report definitions were prioritized where accessible. Publisher records, institutional repositories, and original municipal documents were used to check the sources. The exercise was not a systematic review with a registered protocol, exhaustive database coverage, or a reproducible count of every screened record. It therefore makes no claim to comprehensive coverage or pooled effect estimation. Its methodological strength lies in making the scope of each selected result explicit and tracing the argument from that result to a limited planning inference.

The eligibility boundary concerns publication date, not the date on which a document happens to be hosted or accessed. Only material published before 1 December 2024 informs the analysis; older observations remain identified by their original study periods. An old measurement may still illuminate a mechanism or reveal a methodological problem, but it cannot establish the current composition of a rapidly changing city. Accordingly, the case evidence is interpreted historically and used to develop testable planning propositions. No percentage in the article should be read as a newly measured baseline for a present-day procurement decision. Updating the measurements would be part of implementing the framework, not an unreported step in this review.

Core case selection required a primary source that identified the city, described a collection or sampling boundary, and supplied interpretable material categories. Supporting literature was selected for its relevance to a specific link between composition and program performance. This favors well-documented cases and can exclude cities with severe service needs but limited published research. The comparison consequently describes what the accessible evidence can support, rather than the full distribution of municipal conditions worldwide. This limitation is handled by separating case-specific findings from propositions that could be investigated elsewhere. The latter are analytical claims about decision structure and should be tested with local observations before being treated as established relationships.

Evidence extraction focused on the year of observation, waste source, sampling location, material definitions, mass basis, and relevant service context. Where authors grouped food, vegetation, paper, or other biodegradable materials differently, the original category labels were retained. This procedure sacrifices the apparent simplicity of a uniform composition chart, but a visually tidy chart would be misleading if it silently changed what the categories represented. The comparison therefore uses a compact evidence table and narrative crosswalk rather than a harmonized total. Missing values remain missing, unexplained discrepancies remain visible, and national averages are not substituted for city estimates. These rules preserve the link between a reported number and the population it can describe.

The interpretation distinguishes three levels of claim. A measured finding is tied to its source and sampling frame; a literature-based interpretation identifies a plausible explanation supported by relevant research; a proposed intervention specifies what planners should investigate or test. These levels sometimes appear in the same paragraph because practical analysis requires moving between evidence and judgment. Their proximity can create an impression of greater certainty than the study warrants, so recommendations are stated conditionally and causal language is restricted. The framework and numerical illustration introduced later are original analytical constructions. They organize information and expose assumptions; they are neither newly observed city results nor a validated predictive model.

The comparison also applies a conservative rule to uncertainty. Published point estimates are not assigned confidence intervals unless the source provides an appropriate basis, and differences between the cities are not tested statistically using unrelated sampling designs. This prevents artificial precision but leaves planners with fewer numerical assurances than they might prefer. The appropriate response is to identify which uncertain

variable could alter a decision and collect evidence about that variable. For a collection pilot, uncertainty about storage and route access may be more consequential than a small difference in organic percentage. For a treatment contract, seasonal feedstock quality and accepted throughput may dominate. Evidence appraisal is thus tied to the decision being made, rather than reduced to a single general score for each paper.

Composition Evidence and Source Separation

The first condition concerns how a sample represents the city. Dahlén and Lagerkvist (2008) identify the choice of strata, sample numbers and sizes, sampling location, and sorting categories as central methodological decisions. These choices cannot be reduced to a single prescribed sample mass because surveys address different waste populations and planning objectives. Collecting many kilograms from one convenient location may describe that location carefully while leaving other generators unrepresented. For the present comparison, the appropriate response is to retain the sampling frame alongside each estimate and restrict conclusions to what that frame supports. A market-waste sample can guide a market collection pilot without representing residential waste. A household survey can inform domestic service design without measuring the municipal share attributable to shops. Sampling limitations consequently determine the level of intervention that an estimate can justify, rather than merely adding a caution to an otherwise unrestricted citywide recommendation.

Housing characteristics also matter for interpreting ostensibly city-level composition. Edjabou et al. (2015) examined residual waste from 1,442 households across ten subareas in three Danish municipalities and found differences in food, paper and glass proportions between housing types. The study's spring sampling did not assess seasonal variation, and its households were aggregated into ten composition samples rather than providing 1,442 independent observations. Its contribution is thus methodological rather than a transferable Danish percentage. The evidence supports investigating housing as a sampling stratum, while the limited temporal coverage restricts annual generalization. Applied to the selected cities, this suggests pairing material measurements with building and storage conditions. A city's overall food fraction can coexist with very different possibilities for keeping food separate in an individual dwelling, a shared compound or an apartment building. The relevant planning unit may consequently be a building type or collection zone rather than the whole city.

A second interpretive problem follows directly from the arithmetic of composition. Every percentage has a denominator, and changes elsewhere in the waste stream alter the reported share of a material even when its absolute mass is unchanged. If paper recovery improves while food disposal stays constant, the food percentage of residual waste can rise without any increase in food waste generation. Conversely, a decline in its percentage may reflect an increase in another material. These mathematical possibilities demonstrate why percentage comparisons require accompanying mass flows. The synthesis proposed here is to distinguish composition of generated waste from composition of collected and residual waste, and to interpret each within its own boundary. A high residual organic share can reveal an untreated opportunity; it cannot, by itself, establish unusually wasteful consumption, ineffective collection or the total biological feedstock available to a city.

Material categories introduce a related difficulty. A broad organic fraction may help identify an initial management priority, but its aggregation can conceal differences important to the receiving process. Food scraps, woody garden material and paper cannot be assumed to have identical treatment requirements simply because a classification groups some of them together. Equally, the label plastics does not establish that every item is accepted in the same recycling market. The analytical solution adopted here is to preserve original category labels and aggregate only where the underlying definitions overlap. This approach sacrifices the apparent simplicity of a uniform comparison table in exchange for defensible interpretation. Where a source reports only a broad category, the planning recommendation should identify the missing characterization needed for the next decision. A lack of detail is then treated as a research requirement, rather than filled by an assumed

distribution of materials that the source never measured.

An institutional interpretation is needed because a technically plausible collection scheme can remain financially or organizationally difficult to deliver. Wilson et al. (2012) compare twenty cities through physical service components and governance dimensions, including inclusivity, financial sustainability and institutions. Their purposive comparative design provides a useful analytical structure, but it does not establish a universal sequence through which every city must progress. This article extends that reasoning to composition-led planning: the presence of a recoverable material is only one component of a viable service. Responsibility for containers, collection, enforcement, processing and rejected loads must also be established. Comparing the selected cases consequently requires attention to the organization that makes a material recoverable, rather than treating composition as an independent explanation for performance. The proposed synthesis preserves the material evidence while locating each intervention within the arrangements needed to maintain it after the initial investment.

Household participation similarly depends on the practical work that separation adds to daily routines. Bernstad's (2014) Swedish residential case found no significant improvement after a leaflet intervention, whereas increases followed installation of kitchen sorting equipment and persisted during monitoring. The result supports attention to convenience, although a context-specific intervention cannot demonstrate that information is generally ineffective or establish the improvement achievable elsewhere. The planning implication is to investigate the task at the point where waste arises: available space, handling steps, storage and transfer to the collection point. These features can be assessed without presuming that households with low measured separation lack environmental concern. Composition establishes the material that could be intercepted; observation of household routines identifies the work required to intercept it. A defensible programme therefore joins an appropriately specified collection stream to a usable arrangement for separating that stream before collection occurs.

Information remains relevant when it resolves a specific sorting problem within an accessible service. Rousta et al. (2015) measured improvements following property-close collection and new sorting-information stickers in a Swedish residential area. Their reported changes concerned packaging and newsprint remaining in residual waste and missorted material in food-waste bags, rather than equivalent changes in the overall recycling rate. Possible interaction between interventions also limits claims about a single mechanism. Read alongside Bernstad (2014), this evidence supports a conditional interpretation: communication and infrastructure should be evaluated together, while their functions remain distinguishable. For municipal planning, a message should answer the resident's immediate sorting decision and correspond to the actual collection service. An instruction to separate an accepted item has limited practical meaning if the required receptacle is unavailable, while a nearby receptacle may still receive contaminants when its intended contents are unclear.

Existing recovery arrangements also shape the material available to a proposed service. Wilson et al. (2006) argue that informal recycling can supply economic and resource-recovery benefits that formal planning risks undermining when it disregards established activity. Recognizing those benefits does not imply accepting unsafe work or assuming that all participants benefit equally from existing arrangements. Worker inclusion should consequently be treated as both a distributional issue and a material-accounting requirement. A new collection scheme should identify which materials are already recovered, by whom, and at which stage, before estimating additional recovery. Otherwise, projected municipal gains may include material that was already returning to productive use. The same mapping can identify opportunities for safer collection, agreed access and paid services. These are proposed design considerations, not claims that a particular institutional arrangement has already succeeded in Accra, Dhaka or New York.

The quality of recovered organics deserves separate consideration from the amount collected. Weithmann et al. (2018) detected plastic particles in the biowaste-derived fertilizers they examined, with differences associated with feedstock,

pretreatment and plant conditions. Their findings identify a contaminant pathway; they do not establish identical contamination in all compost or demonstrate health outcomes in the selected cities. A proportionate planning response is to specify acceptance requirements, measure unwanted materials and investigate their entry points. Merely directing more wet mass into biological treatment cannot establish that the resulting material is appropriate for its intended use. The article therefore proposes assessing biological collection through both captured organics and rejected or contaminated material. This distinction allows operational improvement to focus on preserving product usefulness while maintaining participation, rather than treating any increase in separately collected tonnage as an unqualified improvement in recovery performance.

Source separation must also be evaluated against the contribution of downstream sorting. Cimpan, Maul, et al. (2015) review technological developments that can recover materials from commingled recyclables and residual municipal waste, including circumstances where central sorting complements difficult separate collection. This evidence qualifies a simple assumption that increasing the number of household containers always improves recovery. It does not imply that every material retains equivalent quality after mixing, or that a central facility removes the need to understand incoming waste. The practical response is to compare combinations of household separation and subsequent sorting against specified outputs. The number of streams should follow the quality and service requirements of the materials, rather than become a performance target in itself. Where local evidence is insufficient, alternative collection configurations should be tested under realistic conditions before a permanent system commits residents and operators to additional sorting tasks.

Downstream infrastructure can also influence the consequences of changing collection. Cimpan, Rothmann, et al. (2015) model a transition from an efficient waste-to-energy system toward greater separate collection and show that background energy assumptions and wider material movements affect the environmental comparison. Their modeled results cannot be transferred as emission factors to cities with different disposal and energy systems. The relevant lesson is that the treatment displaced by an intervention belongs within its assessment. A source-separated tonne is not an environmental outcome until its destination and the counterfactual destination are specified. For the selected cities, this supports a consistent comparison of collection, processing, rejects and final use or disposal. The proposed decision framework therefore asks what changes across the whole management chain, while keeping uncertain assumptions visible rather than substituting a universal environmental ranking for locally relevant evaluation.

Food-waste prevention complicates the interpretation of successful organics collection in a productive way. Bernstad Saraiva Schott and Andersson (2015) combine a southern Swedish composition study with a hypothetical prevention scenario and find greater modeled global-warming benefits from preventing avoidable food waste than from the assessed treatment alternatives. Neither their avoidable fraction nor their estimated benefits can be assumed for the selected cases. UNEP (2024a) likewise distinguishes food-waste measurement from the additional task of identifying edible and inedible components. Together, these sources show why a planning framework should distinguish food that could have remained in use from unavoidable preparation residues. As an analytical proposal, a successful programme may reduce the amount available for collection while improving environmental performance. Collection targets and plant sizing should therefore allow for prevention rather than depend on maintaining discard quantities. This avoids treating every reduction in organics tonnage as evidence of declining participation when it may reflect a desirable upstream change.

Evidence from Selected Cities

Table 1. Selected composition evidence and its interpretation boundaries

City and source	Observation and waste boundary	Selected reported mass fractions	Constraint on interpretation
Accra Miezah et al. (2015, Table 6)	2013-2014 household pilot; selected neighborhoods; as-collected material.	Organics 65.8%; plastics 10.4%; paper 5.3%.	Household pilot, not all municipal generators. Organics includes food, yard material, wood, and droppings.
Dhaka Alamgir and Ahsan (2007, Table 6)	2004-2005; residential, commercial, institutional, and street-sweeping sources; wet weight.	Organic matter 68.3%; paper 10.7%; plastic 4.3%.	Includes normally sold recyclables retained for sampling. Organic grouping differs from Accra and New York.
New York City New York City Department of Sanitation (2018, p. 28)	2017 residential curbside aggregate discards across collection streams.	Food 20.7%; food-soiled paper 8.1%; yard waste 5.5%; reported organics total 34.4%.	Collected residential boundary; excludes a complete inventory of commercial and other city waste.

Note. Original categories are retained; the percentages are not harmonized. All Accra categories in the source total 100.8%; this discrepancy is preserved, not normalized. New York's displayed organic components sum to 34.3%, while the report gives 34.4% because of rounding. Dhaka places wood with textiles and also lists yard material under "other," limiting category equivalence. Milan is considered separately as implementation evidence.

Accra and the Conditions for an Organics Priority

The Accra evidence supports testing an organics collection service as a substantial component of source-separation planning. Miezah et al. (2015, Table 6) report 65.8% organics, 10.4% plastics and 5.3% paper in their household sample. Yet these observations describe a supported pilot in selected neighbourhoods during 2013-2014, rather than all municipal generators or a present-day citywide material balance. The appropriate inference is therefore a priority for investigation, not a prescribed diversion target. Before estimating vehicles or treatment capacity, planners would need to confirm the quantity that participating households can present separately, the materials a receiving facility will accept, and the collection conditions under which separation remains practical. A composition percentage identifies a potentially important material flow; it does not establish that the flow is available to a particular operator at the quality and frequency required.

An organics service should give households an unambiguous boundary around the materials to be collected. The study classified food residues alongside yard material, wood and animal droppings, while keeping paper separate (Miezah et al., 2015). However, an analytical category is not automatically a valid instruction for a treatment system. A facility receiving readily degradable food residues may require a different preparation process from one receiving bulky woody material; accepting every item described as organic could therefore impose additional handling. A defensible plan would first specify acceptable inputs, then translate those specifications into recognisable household examples. Where an outlet cannot accept particular materials, the collection instruction should exclude them explicitly and provide another route. This makes the operational meaning of separation depend on an actual destination, rather than on an abstract biodegradable/non-biodegradable distinction.

The same evidence offers a useful warning about performance measurement. The Ghana pilot's separation indicator measured the proportion of correctly placed material within each bin (Miezah et al., 2015). High purity would make a collection stream easier to use, but it would not reveal how much of the target material remained in mixed refuse or never entered the service. An Accra pilot should consequently audit

both its separated containers and its residual stream, using the same service boundary and observation period. It should also record which households had access to collection before interpreting low participation as unwillingness. These measurements permit diagnosis: a clean stream that is small relative to independently measured target generation at served premises suggests a capture problem, whereas a substantial contaminated stream suggests a sorting or handling problem. Each result calls for a different intervention and a different estimate of dependable treatment feedstock.

Service reliability deserves a place alongside sorting instructions in that intervention. Yoada et al. (2014) found widespread reported non-separation and complaints about collection cost and irregularity in a surveyed Greater Accra community. Their Madina setting differs from the composition study's localities, so the findings cannot be merged into one representative city dataset. They nevertheless identify questions that a new service should test directly. Would residents continue to hold separated material after a missed collection? Who would clean shared containers, and how would overflow be reported? A pilot that specifies those responsibilities in advance can test whether the service is manageable under ordinary conditions. An education campaign alone cannot resolve an unanswered collection complaint. The planning implication is to treat dependable removal and simple fault reporting as conditions of participation, with public communication explaining both household and operator obligations.

Housing arrangements may require different collection interfaces within a common municipal system. Alhassan et al. (2018) associate separation intentions in Accra and Tamale with factors including inconvenience, space and scheme availability; their cross-sectional design does not establish intervention effects. It would therefore be premature to prescribe a particular number of containers from those associations. A stronger response is to compare feasible arrangements in different dwelling types. Households with suitable storage might use individual receptacles, while shared premises could test assigned communal storage with a clearly responsible caretaker or collection team. Evaluation should include walking distance, time spent handling waste, rejected loads and residents' ability to identify contamination without conflict. Maintaining common acceptance rules while varying the physical arrangement would allow the city to pursue comparable material quality without assuming that every home can perform the same storage routine.

The plastic fraction requires its own investigation even within an organics-first sequence. Its reported mass is evidence that plastics cannot be ignored, but a single percentage does not distinguish products that buyers will accept from contaminated or composite items with no confirmed outlet. A planning team should therefore identify the forms presented by generators, the existing collection relationships, and the buyer specifications before promising recovery. Where an established purchaser accepts a defined material, separate storage may protect its value; where no outlet exists, a new container could merely relocate the disposal burden. Pilot contracts should identify who owns the collected material, who bears rejection costs and how workers are compensated for sorting. These are proposed safeguards against a predictable implementation gap, not findings that the composition study tested. The objective is a usable recovered stream with accountable handling of its rejects.

Dhaka and the Connection to Treatment Markets

Dhaka also presents a substantial case for examining biological recovery, but its evidence has a different boundary. Alamgir and Ahsan (2007, Table 6) report 68.3% organic matter, 10.7% paper and 4.3% plastic by wet weight, from sampling across generator types and seasons in 2004-2005. Those figures cannot be treated as current measurements or directly equated with Accra's household-only profile. They nonetheless support a specific planning question: which identifiable generators could supply an acceptable organic stream at a manageable collection cost? Answering that question requires separate investigation of households, markets, restaurants and institutions instead of imposing a uniform capture assumption on the combined municipal total. A large aggregate fraction strengthens the reason to investigate biological recovery, but the

scale and organisation of a service should follow the verified supply of acceptable material from actual collection areas.

The study's treatment of material normally sold or given to recyclers is particularly relevant to that supply question. Households were asked to retain those materials for characterization (Alamgir & Ahsan, 2007). This improves the visibility of generation, but it means that the measured fraction need not equal what a new municipal contractor could obtain without changing existing transactions. The planning baseline should consequently map where materials already move and avoid counting the same tonnes as both existing recovery and new diversion. If a household sells paper, a municipal programme that collects the same paper has changed the recovery arrangement rather than necessarily increasing recovery. A better performance claim would compare total verified recovery across the original and revised systems. This distinction also creates space for agreements with existing collectors, rather than assuming that municipal access to every generated material is either automatic or desirable.

Dhaka's historical composting experience demonstrates why a prospective outlet matters as much as an organic fraction. Zurbrügg et al. (2005) describe a Mirpur scheme that combined collection, sorting and composting, with bulk buyers and product approval contributing to market development. However, the case involved sorting collected waste and does not establish the performance of citywide source separation. Its relevance is more precise: a recovery system must connect material preparation to a product that someone can use. For a proposed source-separated service, the receiving operator and prospective buyers should agree on quality requirements before collection expands. Incoming-load checks would then protect those requirements, while product testing would show whether they are being met. The transition from organic material to an agricultural input should thus be assessed through verified quality and uptake, not assumed from the amount entering a composting site.

Financial feasibility also depends on the conditions under which the service operates. In the Mirpur assessment, the lower-throughput operation was barely viable, collection fees contributed to financing, and land acquisition was excluded because the site was supplied without charge (Zurbrügg et al., 2005). This historical case cannot justify current prices or a general claim that decentralised composting pays for itself. It does identify a useful structure for appraisal. A proposed facility should show separately its collection income, processing expenses, product revenue, land arrangement and rejected-material disposal costs. It should then test what happens when participation develops slowly or buyers purchase less than expected. Municipal support may be justified where a service provides wider benefits, but that support should be stated explicitly. Transparent financing allows decision-makers to assess a public service rather than mistake a conditional business model for an inherent property of organic waste.

Household participation should be examined with equal care. Afroz's (2011) historical Dhaka study associates available storage space with recycling behaviour, but its selected neighbourhoods and cross-sectional observations do not establish what a contemporary separation service would achieve. The useful planning response is to include storage and handling in service trials rather than use stated willingness as a fixed participation coefficient. A household might support recycling while finding that the supplied receptacle obstructs a cooking area or requires an impractical trip to a collection point. Interviews should therefore accompany physical audits and ask who handles waste, how long it is stored and what happens after missed collection. Testing an arrangement through repeated collection cycles provides a stronger basis for expansion than counting expressions of support before residents have encountered its everyday requirements.

Commercial generators warrant a parallel service assessment rather than being treated as enlarged households. A market or restaurant route could make it easier to identify responsible participants and inspect loads, yet concentration alone does not prove that the material is uncontaminated or economical to collect. Each participating establishment would need an agreed separation point, suitable storage, and a procedure for dealing with unacceptable material. The municipality should compare these routes using accepted material per collection effort, service

reliability and processing rejection, rather than merely the weight delivered. Seasonal changes should be tested within the actual route because citywide or multi-city averages may conceal variation in particular commercial activities. If a concentrated route supplies consistent material, it can support a treatment pilot; if its quality fluctuates sharply, the receiving system and contract must accommodate that uncertainty before further capacity is committed.

New York City and Material Capture

New York City provides evidence that a substantial recoverable fraction can coexist with established separate collection. In residential curbside aggregate discards, the 2017 study reported 20.7% food, 8.1% food-soiled paper, and 5.5% yard waste, with the aggregate organic total reported as 34.4% (New York City Department of Sanitation [DSNY], 2018, p. 28). These figures describe the composition of material collected through the relevant residential system, rather than the composition of every waste flow generated within the city. They therefore identify an opportunity within a defined service boundary; they do not establish a citywide biological-treatment capacity requirement. The planning inference is that organics deserves explicit assessment alongside dry recyclables. Its collection design must still be based on the quantities that households can and will present separately, the material accepted by receiving facilities, and the residual fraction that remains after participation and treatment losses are considered.

The study's sampling design strengthens its usefulness for differentiated service planning: 660 residential samples covered four collection streams, all five boroughs, and three seasons (DSNY, 2018). Nevertheless, breadth of sampling does not erase the distinction between a borough estimate and the operational circumstances of a particular building or route. A city-level mean can identify an important stream while giving little guidance about where extra containers fit or who moves them from storage to collection. Consequently, the next planning step should connect composition estimates to a service inventory rather than treating the average as a universal household profile. Where building audits reveal shared storage, for example, the relevant intervention may require caretaker responsibilities and accessible common collection points. Where dwellings have independent storage, household containers may be more suitable. These are proposed responses to observable service conditions, not conclusions that the compositional survey alone has demonstrated.

Capture rates also expose the gap between classifying a material as recyclable and recovering it through the designated system. DSNY (2018, p. 18) reported a 51.3% capture rate for recyclable paper in 2017. That finding supports investigating losses from an existing stream, but it does not show which particular cause predominates: missing access, sorting errors, inconsistent service, or other circumstances could produce similar aggregate results. A defensible programme would therefore diagnose the location and character of uncaptured paper before selecting a remedy. If residual audits identify clean cardboard concentrated at particular generators, container capacity or collection scheduling becomes a testable intervention. If small mixed-paper items dominate, recognition and convenience may require closer investigation. The synthesis is that composition analysis should generate operational hypotheses and specify their tests. It should not convert an observed recovery gap into an unsupported explanation about residents' attitudes or willingness to cooperate.

The separation of food, yard material, and food-soiled paper in the New York evidence illustrates why a single organic category can be too coarse for service design. These materials may share a possible treatment destination, but their storage requirements, seasonal availability, and handling characteristics need not be identical. Conversely, requiring a different household container for every analytical category would add decisions and storage demands without necessarily improving the quality of the final feedstock. The practical resolution is to distinguish analytical detail from collection instructions. Auditors should retain the detail needed to understand material flows, while planners should combine materials into the fewest operational streams consistent with actual processing specifications. Food-soiled paper, in particular, should not be assigned to an organic stream merely because one

city's classification includes it. The receiving process and its quality requirements must determine eligibility, and the household instruction should express that decision consistently.

Comparative Findings

Across Accra, Dhaka, and New York, the evidence makes biological materials relevant to source-separation planning, but it does not justify treating the reported organic percentages as interchangeable measurements. The underlying studies differ in material categories, sampling locations, dates, and the waste flows represented. A numerical ranking could therefore combine a difference in urban consumption with a difference in what investigators included in the denominator. The defensible comparison concerns planning implications under explicitly preserved definitions. For each city, the analysis should ask whether putrescible material is substantial within the observed stream, what contamination pathways separation could interrupt, and what additional information is required for collection and treatment design. This retains the value of cross-city learning without manufacturing a harmonized dataset. It also makes the uncertainty productive: a missing definition becomes a specific requirement for the next audit rather than a reason to substitute an assumption.

Dry materials require an equally careful comparison because a low observed percentage does not necessarily indicate a low economic or environmental priority. The measured share may reflect the sampling point and any recovery that occurred before the material reached it; a household discard, a collection vehicle, and a disposal site represent different positions in a flow. Conversely, asserting that informal recovery explains every difference would be equally speculative without tracing actual movements. Composition surveys should consequently be paired with a material-flow account that records known removals, collection channels, and destinations. Where these data are unavailable, planners should report the uncertainty explicitly and avoid estimating total generation from residual composition alone. A sound source-separation plan should preserve functioning recovery relationships where they are demonstrated, while addressing losses and unsafe practices identified through local investigation. This requires evidence about who already handles materials, not an assumption that municipal collection begins from zero recovery.

The cases consequently point to different first measurements, even though each raises questions about organic recovery. Accra's supported household pilot makes storage, access, and the distinction between purity and capture immediate uncertainties. Dhaka's wider generator boundary requires an account of source-specific supply and existing recovery transactions. New York's multi-stream residential evidence permits attention to material remaining outside established collection channels. These are analytical priorities, not claims that other concerns are absent in each city. A comparative plan should use those priorities to decide what to measure next: household and residual audits in the first setting, generator and transaction mapping in the second, and matched separated-stream and residual measurements in the third. The comparison becomes useful by changing the next decision, rather than merely adding geographical examples to a general argument.

Milan as an Implementation Comparator

Milan provides an implementation counterpoint to the temptation to interpret high residential density as a decisive barrier to food-waste separation. In their operator-authored conference abstract, Petrone and Vismara (2014) reported approximately 90 kg of food waste collected per inhabitant annually, capture above 86%, and mean contamination of 4.27%. These are performance indicators, not a municipal waste-composition profile, and the abstract does not provide the sampling detail required to treat its precise values as independently verified universal benchmarks. Its contribution is consequently narrower but useful: coordinated food-waste collection was reported to perform well in a setting with substantial multi-occupancy housing. Other cities can use that experience to formulate service trials, but should evaluate those trials against local baselines and documented quality requirements. The appropriate inference concerns feasibility under supporting arrangements, rather than a

prediction that copying Milan will reproduce its reported capture rate.

The reported arrangement combined kitchen containers, compostable bags, shared outdoor bins, communication, and monitoring (Petrone & Vismara, 2014). As a package, these features suggest that household participation was supported at successive points between food preparation and collection. However, the reported outcomes do not isolate the causal contribution of each feature, so they cannot establish that one particular bag or container produced the observed result. The planning task is to examine the continuity of the service. Residents need a practical means to hold the target material, transfer it to an accessible collection point, and expect its removal without remixing. For a city considering this approach, the trial should identify which links are weakest and measure the consequences of changing them. A container distribution programme is therefore incomplete if collection access or operator handling fails, even when the containers themselves are appropriate for the intended material.

The distinction between capture and contamination is especially consequential when assessing apparently successful food-waste programmes. High capture indicates that much of the target material reaches the designated stream, whereas low contamination indicates that relatively little unwanted material accompanies it; neither statistic alone establishes the mass of acceptable output from treatment. Conversely, demanding purity without measuring missed target material could reward a programme that accepts only a small, easy-to-collect fraction. Evaluation should therefore require increased correct capture while keeping impurity within the receiving facility's specification. This should be supplemented by tracking rejects and final destinations. Applied to a Milan-inspired pilot elsewhere, that approach would test whether service changes improve useful recovery rather than merely increasing the weight of a separately labelled collection. It would also prevent a reported capture rate from being treated as an equivalent percentage reduction in final disposal.

Translating Composition into a Source Separation Plan

Material Availability and Recoverable Throughput

The proposed framework begins by separating material availability from the flow that a treatment facility can use. For a clearly defined population and period, let M denote total discarded mass, f the share of a target material within that mass, a the proportion of the target material generated at premises actually reached by the service, c the proportion captured from those served premises, and u the proportion of captured target material accepted into the intended recovery process. Accepted target throughput is then R = M × f × a × c × u. Here f, a, c, and u range from zero to one, and R denotes accepted target input, not finished recycled product. The factors are sequential mass ratios and need not be statistically independent. The expression is an accounting identity, not a fitted empirical law. Its usefulness depends on consistent boundaries and definitions; with those conditions satisfied, it makes explicit why composition alone cannot determine the size of a viable recovery operation.

$$R = M \times f \times a \times c \times u$$

Each factor requires a different kind of evidence. A characterization study can estimate f, while route records and estimates of target generation at served and unserved premises help establish a; separate collection weights and residual audits are needed to estimate c, and processor inspections help establish u. A household participation percentage cannot automatically replace c because households contribute different amounts and may separate only part of the eligible material. Similarly, population coverage cannot replace a without evidence that covered and uncovered populations generate comparable target quantities. A planning model should therefore distinguish the information actually measured from proxies used temporarily. This prevents a well-documented composition fraction from lending false authority to unverified assumptions elsewhere in the calculation. Capture calculated from separated and residual samples is complete only when those streams exhaust the relevant target flow; sales,

home treatment, uncollected waste, and other outlets must otherwise be recorded separately.

Consider an explicitly hypothetical population discarding 1,000 tonnes during a specified period, with a target organic fraction of 60%. If the service reaches premises producing 70% of those organics, captures 65% of the eligible material there, and secures acceptance of 90% of the captured target material, accepted throughput is 245.7 tonnes. These assumed values describe no selected city and are included solely to demonstrate the arithmetic. The 600 tonnes physically present in the starting waste stream do not become 600 tonnes of usable facility input. The calculation shows exactly where the difference arises, allowing a planner to ask whether expansion of coverage, improved capture, or reduced target rejection would most effectively increase usable recovery.

Contamination requires separate accounting because it changes gross collected mass without necessarily changing the mass of correctly captured target material. In the same hypothetical example, captured target material before acceptance is 273 tonnes. If unwanted material represents 10% of the gross separately collected stream, gross collection is approximately 303.3 tonnes, including approximately 30.3 tonnes of contaminants. Applying a 90% acceptance factor to the target material still gives 245.7 tonnes of accepted target material; multiplying gross collection by this target-specific acceptance factor would not estimate accepted target material. In this example, 27.3 tonnes of captured target material are rejected; the fate of the 30.3 tonnes of contaminants remains unspecified. Keeping these flows separate supports credible contracts and avoids rewarding a collection service merely for moving heavier, dirtier loads.

A second hypothetical system illustrates why composition rankings are weak performance rankings. With the same 1,000-tonne starting mass but a 40% target fraction, 95% target-weighted service coverage, 80% capture, and 95% target acceptance, accepted throughput becomes 288.8 tonnes. The smaller target fraction yields more accepted material because the assumed service chain performs better. This is a logical demonstration rather than evidence that any city with a lower organic share will outperform another city. Its practical implication is narrower and more useful: investment appraisal should compare plausible combinations of composition and operational performance. Choosing a facility solely because an audit shows a large biodegradable fraction leaves the principal delivery risks unexamined. This comparison concerns accepted target throughput only; it does not compare costs, emissions, prevention, or the distribution of service benefits.

Table 2. Hypothetical throughput comparison

Assumption or result	Scenario A	Scenario B
Population discards M	1,000 tonnes	1,000 tonnes
Target fraction f	60%	40%
Target-weighted coverage a	70%	95%
Capture at served premises c	65%	80%
Target acceptance u	90%	95%
Captured target material M × f × a × c	273.0 tonnes	304.0 tonnes
Accepted target input R	245.7 tonnes	288.8 tonnes

Note. Author calculation using assumed values; neither scenario represents a measured city. Accepted input is distinct from gross collection, finished product, and avoided disposal. The comparison does not rank environmental, financial, or distributional outcomes.

These equations also identify a data-boundary constraint that cannot be repaired through arithmetic. If M represents residual refuse after existing recycling while f comes from waste before recovery, multiplying the two produces no coherent material estimate. If both describe residual waste, the calculation can instead estimate an additional opportunity within that residual stream, provided existing separated flows are kept outside the denominator. Neither approach is inherently preferable; the decision determines the appropriate boundary. A proposal to improve an existing program needs the recoverable material still being missed, while a whole-system assessment needs all relevant flows. The planner must select and document the boundary before calculating a recovery potential.

Choosing Materials and Collection Streams

The first design decision should concern which materials need protection from mixing. Putrescible organics, marketable dry materials, residual waste, and hazardous household items impose different handling requirements, making a single undifferentiated collection stream a poor informational basis for recovery planning. Adding more household categories, however, also increases storage demands and the number of decisions users must make. A separate stream is justified when the expected gain in material quality or treatment compatibility warrants the additional effort across the collection chain. This rule does not prescribe a universal number of bins. It asks the city to explain the purpose, destination, and operating requirements of every separation it requests.

Low-mass materials also deserve consideration when their consequences are disproportionate to their weight. Batteries, sharps, and chemical containers can create hazards or compromise other streams, even though a mass-based ranking may place them below food and packaging. A dedicated collection route for every infrequent item would be costly and confusing, so the existence of a hazard does not by itself justify another routine household bin. The proposed response is to evaluate scheduled collection, staffed drop-off points, and producer-supported return arrangements against accessibility and safe handling requirements. Composition planning should thus combine a mass assessment with a separate assessment of hazard and interference, keeping both reasons for intervention visible.

Matching Service Design to Premises and Routes

Collection frequency should be derived from the behavior of the material and the conditions in which it is stored. Food-heavy streams raise questions about storage duration, container cleaning, pests, and access that differ from those associated with clean paper or glass. A citywide material percentage cannot determine a safe or acceptable collection interval because storage capacity and environmental conditions vary among premises. Planners should therefore test service intervals in representative building and neighborhood types before standardizing them. The resulting schedule may use frequent organic collection and a different frequency for dry materials, but that arrangement must be demonstrated through local operational evidence rather than assumed from the composition table alone.

Transport should preserve the distinction created at the source. A resident's separation effort contributes little to product quality if collection equipment or transfer operations subsequently mix incompatible streams. Maintaining separate loads can increase costs or reduce vehicle utilization, however, especially where quantities are initially small. The practical synthesis is to assess route sequencing, compartments, transfer storage, and collection days together with household instructions. A pilot should document what happens to each stream after the container is emptied, not merely whether the container was provided. This requirement connects the apparent simplicity of household sorting to the operational arrangements that allow the separated material to retain its value.

Service expansion should also account for residents whose waste is poorly represented in formal collection records. Starting with accessible premises may produce useful operational learning, but using only those premises to forecast the costs and capture rates of a citywide service can understate the difficulty of reaching excluded areas. The framework therefore treats coverage as both a performance variable and a distributional question. Pilots should include contrasting access

conditions or clearly limit their forecasts to the environments observed. A successful demonstration in a convenient service area can justify learning and further trials; it does not, by itself, establish the feasibility or fairness of an entire municipal rollout.

Treatment Compatibility and Environmental Performance

Treatment selection should follow an assessment of reliably available feedstock and acceptable outputs. Organic-rich waste creates a plausible case for biological processing, yet neither a composition percentage nor the term biodegradable establishes the suitability of a particular composting or anaerobic digestion configuration. The review by Bernstad and la Cour Jansen (2012) shows that comparative food-waste life-cycle results depend strongly on boundaries, input assumptions, and treatment-related processes. The planning implication is to compare locally specified alternatives using the same material and service boundary. Electricity substitution, transport, process losses, and the actual use of compost or digestate should enter that comparison explicitly rather than being hidden inside a generic claim of environmental superiority.

Acceptance at a facility is an intermediate outcome rather than proof of useful circularity. A plant can receive a clean stream and still face operational losses or difficulty finding an appropriate destination for its output. Conversely, the final mass of compost cannot be compared directly with the incoming wet mass as though all mass loss represented failure, because biological treatment transforms material. The proposed performance structure records accepted input, process rejects, product quality, and documented destination separately. This approach avoids inflating recovery by counting every incoming tonne as a finished resource, while also avoiding the opposite error of judging biological treatment solely by the mass retained after processing.

Implementation and Evaluation

Pilot design should make comparisons informative rather than merely produce an attractive success rate. Selecting willing participants can reveal whether a service is workable under favorable conditions, but it cannot estimate ordinary participation across a heterogeneous city. Where feasible, trials should document baseline material flows and compare different service arrangements in similar areas, while recording differences in building type and existing collection. Random allocation may strengthen causal inference, although operational constraints can make it impractical. The essential requirement is to match the strength of the conclusion to the design: a demonstration establishes possibility, a well-constructed comparison supports an intervention effect, and neither should automatically be presented as a citywide forecast.

Evaluation should distinguish service delivery, user response, material quality, and recovery outcome. The multidimensional Wasteaware framework provides a relevant precedent (Wilson et al., 2015). Collection completion and access records explain whether the service operated; target quantities in separated and residual streams reveal capture; load inspections reveal contamination; and processor records show accepted throughput. A large dashboard can overwhelm a municipal team and encourage incomplete reporting, so indicators should be selected around actual management decisions. For example, low capture combined with clean loads suggests a different response from high capture combined with heavy contamination. The value of the measurement system lies in that diagnostic distinction. Each indicator should tell an operator or policymaker what additional investigation or corrective action is warranted.

Table 3. Diagnostic decisions for source-separation programs

Observation	Possible explanations	Next measurement	Conditional response
Clean stream, low target yield	Limited access; low capture; low generation or prevention.	Target-weighted coverage and matched residual audit.	Expand access or redesign handling only after confirming a recovery gap.
Heavy, contaminated stream	Missorting at source; mixing in collection.	Paired samples at containers and vehicle discharge.	Revise instructions or collection handling at the identified point.
Accepted feedstock, unsold product	Product quality; weak demand; unsuitable specification.	Product tests and verified sales or use records.	Improve processing or revise capacity and outlet commitments.
Organic percentage increases	More organic mass; reduced mass of other fractions.	Absolute mass of each fraction on a consistent basis.	Reassess organic capacity only if relevant throughput changes.

Note. Author synthesis. These are diagnostic hypotheses and proposed responses, not observed intervention results in the selected cities.

Financial appraisal should include the cost of obtaining usable material rather than collection expenditure alone. More frequent collection or additional staff may appear inefficient when compared only by gross tonnes transported, while reducing contamination and improving acceptance can alter the cost per accepted tonne. Revenue assumptions introduce another uncertainty because product prices and demand may change. A defensible appraisal therefore separates service costs, avoided disposal costs, treatment charges, and expected revenues, and tests their consequences under less favorable assumptions. The article does not assign monetary values to these components because comparable city-specific data have not been established. The contribution is the structure of the calculation and the requirement that its uncertainties remain visible.

Affordability should be evaluated from the standpoint of both the service provider and its users. A tariff that covers collection expenditure can still impose a disproportionate burden on households with limited income, while an apparently inexpensive service may transfer substantial unpaid handling work to residents or caretakers. Those burdens cannot be inferred from a composition audit, and reducing charges without a financing plan may undermine reliability. A pilot should therefore document fees, time requirements, accessibility, and responsibility for cleaning, alongside operating expenditure. Where subsidies or differentiated service arrangements are proposed, their beneficiaries and financing should be explicit. This makes distributional assessment a practical part of program design: the municipality can examine who gains access, who performs additional work, and whether the arrangement remains affordable without relying on an average participation rate to represent every household.

Municipal contracts should allocate responsibility for failures at the point where they can be controlled. Residents influence sorting, collectors influence stream integrity, building managers influence storage and access, and processors establish acceptance requirements. Assigning all contamination costs to one participant may be administratively simple while creating unfair penalties or encouraging concealment. Contracts and monitoring should therefore identify the relevant material specification, inspection method, feedback procedure, and response to rejected loads. This is a proposed governance implication of the material-flow analysis, not a claim that a single contractual arrangement has been proven superior. Its purpose is to prevent a technically appropriate separation scheme from failing because responsibilities remain undefined.

Transparent reporting should also account for the uncertainty introduced by moisture and

seasonal changes. A heavier collected organic load could reflect more captured food, more rainwater, a different seasonal mix, or some combination of these factors. Treating every increase as behavioral success would obscure the mechanism that managers need to understand. Repeated sampling, consistent collection periods, and records of unusual conditions can improve interpretation without requiring exhaustive laboratory analysis of every load. The appropriate level of monitoring depends on the decision, but it must be sufficient to distinguish genuine capture improvements from changes in the measurement basis. This principle is especially important when performance payments are linked to tonnage.

Discussion and Research Priorities

The article also exposes a tension between standardization and local relevance. Comparable categories and reporting conventions can improve learning across cities, but imposing an identical survey structure can miss locally important materials, informal recovery routes, and service arrangements. A useful research strategy would retain common high-level categories while allowing documented local subdivisions and separate reporting of prior recovery. This would permit comparison at the level genuinely shared by the datasets without erasing differences that matter operationally. The proposal requires testing, particularly where analytical capacity is limited. It is presented as a direction for methodological development rather than as a standardized protocol already validated by the present review.

Several limitations define the scope of the conclusions. Case selection is purposive, study dates differ, composition categories remain partly incompatible, and the review does not provide new measurements of participation, costs, or treatment performance in the selected cities. These limits prevent a statistical generalization, a current city ranking, or an investment-ready feasibility estimate. They do not invalidate a comparative examination of measurement boundaries and planning logic, provided those boundaries remain explicit. The value of the article lies in identifying claims that the evidence can support and exposing assumptions that would require additional investigation. Its recommendations are strongest as a guide to designing that investigation and avoiding premature commitment.

Future empirical work should test the framework by measuring the same target materials through the entire service chain. Repeated audits of generated, separated, residual, and rejected material could reveal where recoverable quantities are lost and how those losses differ by building and service type. Such studies are more demanding than a one-time composition survey and may require collaboration among households, collectors, and processors. A practical response is to concentrate detailed measurement in representative routes while maintaining simpler records across the wider service. This would allow researchers to test whether interventions change capture or acceptance, rather than assuming that a favorable change in one reported percentage proves overall improvement.

Conclusion

Municipal waste composition can guide source-separation planning when the measurement describes a known population, material boundary, and period. The selected evidence for Accra, Dhaka, and New York City establishes useful opportunities for investigating different material streams, while its methodological differences prevent a defensible ranking based on organic percentages alone. Milan adds evidence relevant to implementation without supplying an interchangeable composition estimate. The combined interpretation is that source separation requires both a material diagnosis and an operational account of how that material will move. A composition table becomes actionable when planners connect it to actual service access, capture, contamination control, treatment acceptance, and the destination of recovered products.

The comparative framework separates material present from material reliably accepted for recovery. The proposed accounting expression makes coverage, capture, and acceptance visible, and the hypothetical example shows why a larger target fraction need not produce greater usable throughput. The framework remains a planning aid rather than a validated prediction model, so its parameters require local measurement and its outputs should be tested against observed flows.

Used with that limitation, it offers a disciplined way to compare interventions, identify consequential uncertainties, and decide where additional evidence is worth collecting. It also reduces the risk of designing facilities around quantities that exist in a survey but never arrive as suitable feedstock.

Source-separation policy should consequently proceed through clear material specifications, accessible collection arrangements, protected transport, and accountable downstream recovery. Standardization can simplify communication and management, yet differences among premises, neighborhoods, and existing recovery practices require justified adaptations. The appropriate municipal objective is dependable recovery within an equitable service, alongside prevention of avoidable discards. Achieving that objective requires repeated measurement and adjustment rather than treating the first characterization study as a permanent prescription. The selected cities contribute distinct evidence to this conclusion; the broader contribution is a method of reasoning that allows other municipalities to use their own evidence more carefully and productively.

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