

## **COLLECTION BEFORE COMBUSTION: WASTE COMPOSITION, ENERGY RECOVERY AND THE SEQUENCING OF WASTE INFRASTRUCTURE**

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### **Article History**

Received: 23-08-2025

Revised: 21-09-2025

Accepted: 16-10-2025

### **Keywords:**

Municipal Solid Waste;  
Waste-to-Energy; Calorific  
Value; Collection Coverage;  
Informal Recycling

### **ABSTRACT**

Waste-to-energy is widely proposed as the solution to municipal solid waste in rapidly urbanising countries, and it is usually proposed before the collection and separation systems that determine what a plant would burn. This study examines that sequencing. The method combines a structured review of research published between 2017 and 2024 with a synthesis of published composition and calorific data. Three findings follow. The dominant loss pathway in lower-income settings is uncollected waste rather than consumer behaviour: a global inventory across 50,702 municipalities estimates plastic waste emissions at 52.1 million tonnes annually, approximately 57 per cent of it open-burned, and finds littering dominant in the Global North while uncollected waste dominates the Global South. Composition makes combustion conditional rather than universal, since sampled waste in one African city was 80 per cent organic with a lower heating value of 6.12 megajoules per kilogram at 25 per cent moisture, and organic content in one Asian dumpsite fell from 70.5 per cent when fresh to 0.35 per cent after fifteen years with calorific value declining alongside it. And each upstream step alters the feedstock of the next, so a plant sized before collection, separation and organic diversion are settled has fixed its design feedstock before that feedstock is determined. The study proposes a five-step sequencing criterion and specifies what must be measured before thermal capacity is committed.

### **ABSTRAK**

Pengolahan sampah menjadi energi kerap diusulkan sebagai jawaban atas persoalan sampah kota di negara-negara yang mengalami urbanisasi cepat, dan biasanya diusulkan sebelum sistem pengumpulan dan pemilahan yang menentukan apa yang akan dibakar itu sendiri tersedia. Penelitian ini menelaah urutan tersebut. Metodenya memadukan telaah terstruktur riset terbitan 2017 hingga 2024 dengan sintesis data komposisi dan nilai kalor yang telah dipublikasikan. Tiga temuan mengikutinya. Jalur kehilangan yang dominan di negara berpendapatan rendah adalah sampah yang tidak terangkut, bukan perilaku konsumen: inventarisasi global atas 50.702 wilayah administratif memperkirakan emisi sampah plastik 52,1 juta ton per tahun, sekitar 57 persen di antaranya dibakar terbuka, dan menemukan pembuangan sembarangan dominan di negara utara sementara sampah tak terangkut dominan di negara selatan. Komposisi membuat pembakaran bersifat bersyarat, bukan universal, sebab sampah tersampel di satu kota Afrika mengandung 80 persen bahan organik dengan nilai kalor bawah 6,12 megajoule per kilogram pada kadar air 25 persen, dan kandungan organik di satu tempat pembuangan terbuka di Asia turun dari 70,5 persen saat segar menjadi 0,35 persen setelah lima belas tahun, dengan nilai kalor yang menurun seiring itu. Setiap langkah hulu mengubah

|  |                                                                                                                                                                                                                                                                                                                                                                                                                                             |
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|  | umpan bagi langkah berikutnya, sehingga fasilitas yang ukurannya ditetapkan sebelum pengumpulan, pemilahan, dan pengalihan organik selesai telah mengunci umpan desainnya sebelum umpan itu ditentukan. Penelitian ini mengusulkan kriteria pengurutan lima langkah dan merinci apa yang harus diukur sebelum kapasitas termal dikomitmenkan.<br>Kata kunci: sampah kota; sampah menjadi energi; nilai kalor; cakupan pengumpulan; pemulung |
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## 1. INTRODUCTION

A city with a waste problem is offered a plant. The proposal is attractive because it converts a liability into electricity, occupies a defined site, and can be financed, built and inaugurated within a political term. The systems it depends on — collection vehicles, transfer stations, separation at source, organic diversion — are diffuse, unglamorous, and produce no ribbon to cut.

This study is about the consequence of that asymmetry. Thermal treatment is not a general solution to municipal waste; it is a treatment for a particular kind of residual material, and whether a city's waste is that kind of material is determined by everything upstream of the plant. Building the plant first does not merely reverse a sensible order. It commits a design feedstock before the feedstock exists.

The scale of the underlying problem is not in doubt. Cottom et al. (2024), using machine learning and probabilistic material flow analysis across 50,702 municipalities worldwide, estimate global plastic waste emissions at 52.1 million tonnes annually within a 95 per cent range of 48.3 to 56.3 million tonnes, with approximately 57 per cent by weight open-burned and 43 per cent unburned debris. Their distributional finding is the one that should govern policy: littering is the largest emission source in the Global North, whereas uncollected waste dominates in the Global South.

That distinction identifies the binding constraint. Where the dominant loss pathway is uncollected waste, the first-order problem is that material never enters the managed system at all, and a treatment plant at the end of that system cannot treat what does not reach it. Amulen et al. (2022) report global generation rising toward 3.4 billion tonnes by 2050 against roughly 1.9 billion tonnes annually at present, so the quantity that must be brought into the system is growing rather than stable.

Composition compounds the sequencing problem. Amulen et al. (2022) found sampled waste in one African city to be 80 per cent organic with a lower heating value of 6.12 megajoules

per kilogram at 25 per cent moisture. Nanda and Berruti (2021) state the general pattern: low- and middle-income populations generate mainly organic waste while high-income populations produce more paper, metals and glass. Incineration technology developed for the second is being proposed for the first.

Three questions organise the analysis. First, what do the verified data establish about the composition and calorific value of municipal waste in lower-income settings, and how do these change with handling and with age? Second, under what conditions does energy recovery become technically and economically viable, on the evidence available? Third, what sequencing follows, and what must be measured before thermal capacity is committed?

## **2. LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK**

### **Generation, emission pathways and collection**

Cottom et al. (2024) provide the most comprehensive emissions inventory located, combining machine learning with probabilistic material flow analysis across 50,702 municipalities and five land-based emission sources. Beyond the aggregate estimate, their finding that uncollected waste dominates in the Global South while littering dominates in the Global North reframes the policy target: in one setting the problem is behaviour at the point of discard, in the other it is the absence of a system to discard into.

Amulen et al. (2022) supply the generation context, reporting global municipal solid waste rising toward 3.4 billion tonnes by 2050 from approximately 1.9 billion tonnes annually, at around 218 kilograms per person per year. Their figures differ from other widely cited series and are reported here as published rather than reconciled with them; the trajectory rather than the exact level is what the argument uses.

Vaverková (2019) reviews landfill impacts and makes an observation that constrains any argument for rapid transition: sanitary landfilling or open dumping remains dominant in most countries because of relatively low cost and low technical requirements, and a waste management system operating with no landfilling at all is unrealistic within one generation, since some residual fraction will always require disposal. Any proposal that treats disposal as eliminable is proposing something the review literature does not support.

### **Composition, moisture and calorific value**

Amulen et al. (2022) characterise sampled waste in Kampala as 80 per cent organic, with a lower heating value of 6.12 megajoules per kilogram, moisture of 25 per cent and ash of 6.65 per cent, and elemental composition of 43.47 per cent carbon, 5.52 per cent hydrogen and 41 per cent oxygen with nitrogen and sulphur absent. That combination — high organic fraction, substantial moisture, moderate heating value — is the characteristic profile the incineration literature was not developed around.

Temaja et al. (2024) characterise waste in an Indonesian city for gasification, reporting on a dry basis moisture of 12.45 per cent, volatile matter of 54.68 per cent, fixed carbon of 13.05 per cent and ash of 19.82 per cent, with a calorific value of 11.99 megajoules per kilogram, and conclude that gasification-based recovery is feasible for that city's waste. The figure is substantially higher than the Kampala value, and the reason is methodological rather than geographic: the analysis was conducted on a dried sample, so the value is not comparable with as-received waste and should not be treated as the heating value a plant would encounter.

Mondal and Rafizul (2024) establish that composition is not fixed even for a given city. Examining waste of different ages at an open dumpsite, they find organic content falling from 70.548 per cent in fresh material to 0.35 per cent in fifteen-year-old waste while plastic content stays roughly constant after an initial rise; moisture and volatile content decline with age while fixed carbon and ash rise; and calorific value declines with age. They also report unit weight falling from 9.31 to 4.668 kilonewtons per cubic metre, which bears on dumpsite stability.

Nanda and Berruti (2021), reviewing management and landfilling technologies, state the income gradient in composition directly: low- and middle-income populations generate mainly organic waste while high-income populations generate more paper, metals and glass. Kumar and Samadder (2017) and Malinauskaite et al. (2017) review the technological options for energy recovery and the European experience of waste-to-energy within a circular economy respectively; they are cited here for the scope of the field rather than for specific parameters.

### **Energy recovery: conditions and economics**

Amulen et al. (2022) provide the fullest verified economic assessment located. Modelling a mass-burn plant at 220,000 tonnes per year, equivalent to 27 tonnes per hour, they estimate export of 774 kilowatt-hours of electricity per tonne of waste, sufficient for 1,062 medium-

income households, against capital expenditure of 157 million United States dollars, a net present value of 30 million dollars, an internal rate of return of 12.6 per cent and a payback period of six years, with 75 per cent debt financing over fifteen years.

Two Indonesian conference studies supply local cost and viability figures and are identified as conference papers rather than journal articles. Farizal and Tammarar (2019) determine an ideal tipping fee for one city of 97,704 rupiah per tonne, falling to 40,032 and 63,337 rupiah per tonne under two scenarios that add a landfill gas bioreactor, because the additional revenue reduces the fee required. Mohammad et al. (2020), assessing a landfill in another Indonesian city against the 2016 presidential regulation on accelerating waste-based power generation, find that only a standard reciprocating engine-generator configuration breaks even on electricity sales alone, at six years after operations begin with a net present value of 755,664 dollars over a fifteen-year project life.

The thinness of that margin is the finding worth carrying forward. A configuration that breaks even only in its sixth year on a fifteen-year life has little tolerance for a feedstock that turns out wetter, more organic or less abundant than the design assumed — which is precisely the risk created by committing capacity before the upstream system is settled.

### **The informal sector and what it already recovers**

Morais et al. (2022) review 45 papers published between 1994 and 2022 covering case studies from 27 countries, coded against poverty, health, stigma, environmental factors, informality and formalisation. Their central conclusion is that formalisation can deliver legal recognition, safe working conditions and fair bargaining, but that formalisation policies differ greatly between countries and often fail to deliver those benefits, while waste pickers' contribution to circular economy goals has been systematically undervalued. Aparcana (2017) reviews barriers to and success factors for formalising the informal sector in low- and middle-income countries.

Watanabe et al. (2018) identify a mechanism with direct bearing on the sequencing argument. Comparing landfill recycling in two Southeast Asian countries, they find that in the Indonesian case the main item recovered at the landfill is plastic bags, because more valuable materials have already been stripped out upstream before waste arrives, whereas landfills in the comparator country still contain bottles and metal cans and pickers therefore earn more. They argue authorities should support recovery further upstream so that landfill picking becomes unnecessary.

Putri et al. (2018) quantify the Indonesian recovery system in one city through material flow analysis, finding a plastic recycling rate of 24 per cent with 76 per cent of plastic waste going to landfill or the environment, and recovery split between individual scavengers at 239 kilograms per month and community waste banks at 260 kilograms per month. Velis and Cook (2021) review the occupational and public health risks of open burning of plastic waste with emphasis on the Global South.

### **Separation at source and producer responsibility**

Rousta et al. (2020) meta-analyse twelve factors influencing household waste sorting participation in developing countries and find the strongest correlations with attitude, moral norm, subjective norm and perceived behavioural control, with knowledge, situational conditions and governmental incentives also influential. Their most useful result for programme design is negative: socio-demographic factors had the weakest influence despite being the most studied, so separation programmes should not be built around demographic targeting.

Kardian et al. (2021), in a conference study of post-consumer plastic packaging in Indonesia, identify the constraints as limited regional waste management capacity, inadequate infrastructure, weak implementation of regulations and low public and industrial concern, and report that extended producer responsibility implementation in developing countries remains weak with collection and recycling systems inadequately addressed.

### **Collection is a metropolitan service governed at municipal scale**

Waste collection is organised by municipality and generated by a settlement pattern that crosses municipal boundaries, which places it within the metropolitan governance problem rather than outside it. Moore-Cherry et al. (2022), reviewing the literature between 2014 and 2019, find broad agreement that the metropolitan scale is appropriate for coordinated land management alongside no agreement on the mechanisms that would deliver it, with territorial politics and power imbalances the recurring obstacles.

Beghelli et al. (2020) quantify the spatial consequence of fragmented governance across 180 cities over twelve years, finding that fragmentation increases inter-municipal competition for residents and business and raises land consumption. For a collection system, a larger and less dense serviced area raises haulage cost per tonne, so governance fragmentation enters

waste economics through the settlement pattern it produces before it enters through coordination failure.

Sahana et al. (2023), reviewing 3,124 publications of which 56 address the question directly, conclude that no generalised method exists for demarcating the peri-urban, with approaches varying by land use, socioeconomic condition and political system. The finding matters operationally: the zone in which collection coverage is weakest is also the zone that no standard definition delineates, so the population outside the managed system is difficult to size even in principle.

### **Projecting where the waste will be generated**

Three studies establish that the settlement pattern driving future collection demand is projectable with standard methods. Mithun et al. (2022) compare three modelling techniques for one metropolitan area, finding a neural network approach performing best with a Kappa coefficient of 0.9025 and projecting built-up coverage rising from thirty-one to fifty-five per cent across two decades. Arifin et al. (2023) model peri-urban conversion around an Indonesian coastal city and project built-up land reaching 67.27 per cent of the study area for a population of approximately two million.

The design implication is that collection coverage can be planned against a projected service area rather than extended reactively behind settlement. This matters more for waste than for most services, because the cost of collection rises with distance and falls with density, so the sequence in which peri-urban areas are brought into the system determines the average cost of the whole system rather than only the cost at the margin.

### **Monitoring what the system does not capture**

Two studies demonstrate that material flows outside a managed system are now observable at low cost. Nascimento et al. (2020) apply object-based image analysis to high-resolution imagery to quantify land-cover change and revegetated area across extraction complexes without site access. Diaconu et al. (2023) combine satellite imagery with uncrewed aerial survey to identify unlicensed extraction and quantify removed volumes at individual sites, at costs within the reach of an enforcement agency.

The transferability to waste is direct. Open dumping sites and their growth are surface features of the same kind, and a municipality that cannot measure how much waste it collects can nonetheless measure how much accumulates where it does not. Given that

uncollected waste rather than consumer behaviour is the dominant emission pathway in lower-income settings, an inventory built from imagery of unmanaged accumulation would measure the quantity that matters, which tonnage records at a weighbridge by construction cannot.

### **Research gap**

Four gaps shape this study. The composition literature and the energy recovery literature are rarely brought together with the collection literature, so the sequencing question is not usually posed. No verified peer-reviewed source within the review window reports Indonesian national waste generation, per capita generation or collection coverage, so no national figure is offered here. No verified source quantifies waste-to-energy air emissions, which is the principal objection to incineration, so that dimension is absent rather than assessed. And no verified source quantifies the share of national recovery delivered by informal pickers, so their contribution is described qualitatively.

## **3. METHOD**

The study is a structured review with a synthesis of published composition and economic data. It generates no primary data, samples no waste, and models no facility.

### **Source identification and verification**

Peer-reviewed studies published between 2017 and 2024 on municipal solid waste generation and composition, energy recovery, landfill impacts, informal recovery and source separation were identified and retained only where bibliographic details could be verified against a publisher page, an indexing database record or a digital object identifier record. Sources whose findings could not be read directly are cited only at the level their titles support, and this is stated at the point of use. One heavily cited review was excluded because its journal was removed from a major citation index during the review period. Conference proceedings are identified as such wherever used.

### **Treatment of composition and economic data**

Composition and calorific figures are reported as published from a single identified source, with the analytical basis stated. Values determined on dried samples are not compared with as-received values, and the distinction is made explicit wherever both appear. Economic figures are reported in the currency and year given by their source and are not converted or

inflated. Where two sources report irreconcilable values for the same global quantity, both are stated with their sources.

### The sequencing framework

The analysis treats a waste system as five steps in which the output of each determines the input of the next: collection coverage, source separation, organic diversion, residual characterisation and thermal treatment. For each step, the analysis asks what it changes about the material reaching the next step and what would have to be known for a downstream investment decision to be sound. The framework is analytical and is not derived from any single jurisdiction's practice.

## 4. RESULTS AND DISCUSSION

### The binding constraint is collection

**Table 1. Verified global quantities**

| Quantity                                         | Value                                  | Source               |
|--------------------------------------------------|----------------------------------------|----------------------|
| Municipalities in the global emissions inventory | 50,702                                 | Cottom et al. (2024) |
| Global plastic waste emissions                   | 52.1 Mt per year (95% range 48.3-56.3) | Cottom et al. (2024) |
| Share open-burned                                | Approximately 57 per cent by weight    | Cottom et al. (2024) |
| Dominant source, Global North                    | Littering                              | Cottom et al. (2024) |
| Dominant source, Global South                    | Uncollected waste                      | Cottom et al. (2024) |
| Global municipal solid waste generation          | Approximately 1.9 billion t per year   | Amulen et al. (2022) |
| Projected generation by 2050                     | 3.4 billion t                          | Amulen et al. (2022) |
| Generation per person                            | Approximately 218 kg per year          | Amulen et al. (2022) |

*Source: compiled by the authors. The generation figures differ from other widely cited series and are reported as published rather than reconciled.*

The fourth and fifth rows carry the argument. Where uncollected waste is the dominant emission source, the material causing harm is material that never entered the managed system. A treatment facility is a device for processing what the system captures; it has no effect whatever on what the system misses. Investment sequenced to build treatment before collection therefore addresses the smaller share of the problem first.

The third row adds a second consideration. If approximately 57 per cent by weight of plastic emissions are already being open-burned, then uncontrolled combustion is the current default in much of the world, and Velis and Cook (2021) review its occupational and public

health risks. That is an argument for controlled treatment — but it is an argument that becomes operative only once material is collected, since open burning occurs precisely where collection does not reach.

### Composition makes combustion conditional

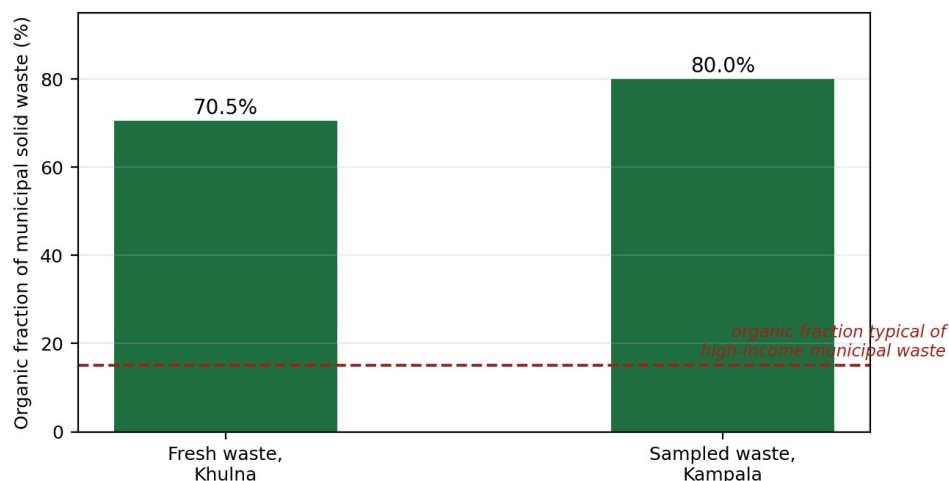


Figure 1. Organic fraction of municipal solid waste in two studied cities (sources: Amulen et al., 2022; Mondal & Rafizul, 2024)

**Table 2. Verified composition and calorific data**

| Parameter                                | Value                           | Basis and setting                 | Source                  |
|------------------------------------------|---------------------------------|-----------------------------------|-------------------------|
| Organic fraction                         | 80 per cent                     | Sampled waste, Kampala            | Amulen et al. (2022)    |
| Lower heating value                      | 6.12 MJ/kg                      | Same sample, 25 per cent moisture | Amulen et al. (2022)    |
| Moisture                                 | 25 per cent                     | Same sample                       | Amulen et al. (2022)    |
| Organic fraction, fresh waste            | 70.548 per cent                 | Open dumpsite, Khulna             | Mondal & Rafizul (2024) |
| Organic fraction, fifteen-year-old waste | 0.35 per cent                   | Same dumpsite                     | Mondal & Rafizul (2024) |
| Unit weight, fresh to aged               | 9.31 to 4.668 kN/m <sup>3</sup> | Same dumpsite                     | Mondal & Rafizul (2024) |
| Calorific value                          | 11.99 MJ/kg                     | Dried sample, Denpasar            | Temaja et al. (2024)    |
| Moisture                                 | 12.45 per cent                  | Dried sample, Denpasar            | Temaja et al. (2024)    |

Source: compiled by the authors. The Denpasar values were determined on a dried sample and are not comparable with as-received values; they are reported with that basis stated.

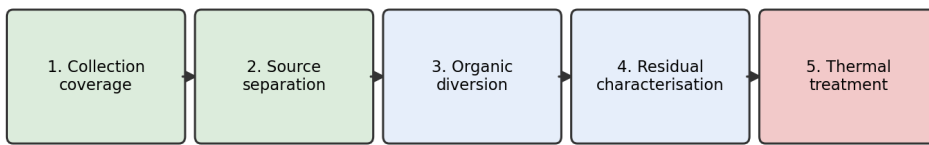
The first three rows describe the profile that governs feasibility. A lower heating value of 6.12 megajoules per kilogram at 25 per cent moisture is combustible but unforgiving: moisture must be evaporated using energy the waste itself supplies, so the net export is sensitive to any increase in water content. An 80 per cent organic fraction is also the fraction most

readily diverted to composting or digestion, which means the material with the lowest energy value is the material most easily removed from the stream before it reaches a furnace.

The comparison between the last two rows and the first two illustrates the analytical trap this study warns against. A calorific value of 11.99 megajoules per kilogram determined on a dried sample looks like a comfortable margin over 6.12 megajoules per kilogram on as-received waste; the difference is substantially the water that was removed before analysis. A feasibility case built on dry-basis values for a plant that will receive wet waste overstates the resource.

Mondal and Rafizul's (2024) ageing result adds a temporal dimension that plant siting rarely considers. Organic content falling from 70.5 per cent to 0.35 per cent across fifteen years, with calorific value declining alongside it, means that mining an existing dumpsite yields material with different properties from fresh collection, and that a facility designed to consume both is designed for two different fuels. The accompanying fall in unit weight from 9.31 to 4.668 kilonewtons per cubic metre is a separate geotechnical finding that bears on the stability of aged dumpsites.

Sequencing



Each step changes the composition and calorific value of what reaches the next.

*Building step 5 first fixes a plant's design feedstock before steps 1 to 4 have determined it.*

Figure 2. Five steps in which each output determines the next input (authors' construction)

Table 3. What each step changes and what must be known before committing to the next

| Step                | What it changes about the material         | What must be measured before proceeding                |
|---------------------|--------------------------------------------|--------------------------------------------------------|
| Collection coverage | How much material enters the system at all | Tonnes collected against tonnes generated, by district |
| Source separation   | Removes recyclables and contaminants       | Capture rate by material;                              |

|                           |                                            | contamination rate                                     |
|---------------------------|--------------------------------------------|--------------------------------------------------------|
| Organic diversion         | Removes the wettest, lowest-value fraction | Diverted tonnage; residual moisture after diversion    |
| Residual characterisation | Establishes the actual fuel                | As-received calorific value, moisture, ash, seasonally |
| Thermal treatment         | Converts residual to energy and ash        | Design feedstock confirmed against measured residual   |

*Source: authors' framework. The third column states the minimum measurement each step requires before the next is committed.*

The framework's claim is narrow and, stated plainly, hard to dispute: the calorific value of the material reaching a furnace is determined by the four steps before it. A plant sized and contracted before those steps are in place has fixed a design feedstock while the variables that determine the actual feedstock remain open. If separation and organic diversion then succeed, the residual is drier and higher in calorific value but smaller in quantity than the design assumed; if they fail, the quantity is met but the fuel is wetter. Both outcomes are adverse for a facility whose economics, on the Indonesian evidence, break even only in the sixth year of a fifteen-year life.

The fourth row deserves emphasis because it is the step most often skipped. Residual characterisation means measuring what remains after separation and diversion, on an as-received basis, across seasons. The two Indonesian characterisation results available illustrate why the basis matters: a dry-basis figure and an as-received figure differ by roughly the water content, and only the second describes what a plant will burn.

Long-term contracts compound the exposure. A facility procured with a minimum tonnage guarantee converts upstream success into a financial penalty, because separation and diversion reduce the tonnage the municipality is contractually obliged to deliver. That is not an argument against thermal treatment; it is an argument for sequencing the contract after the upstream system rather than before it.

### **The recovery system that already exists**

A city considering thermal treatment already has a recovery system, and it is largely informal. Putri et al. (2018) measure it in one Indonesian city at a 24 per cent plastic recycling rate, with individual scavengers recovering 239 kilograms per month and community waste banks 260 kilograms per month, leaving 76 per cent of plastic waste in landfill or the environment.

Watanabe et al.'s (2018) comparative finding explains what that system does to downstream material. In the Indonesian case the principal item recovered at the landfill is plastic bags, because more valuable materials have been stripped out upstream; in the comparator country, bottles and cans still reach the landfill and pickers earn more. Upstream recovery therefore already removes the higher-value plastics from the stream, which means the residual arriving at a disposal site is poorer in exactly the fraction that carries the highest calorific value.

This is a second reason for measuring residual composition rather than gross composition. It also raises a distributive question that formalisation does not automatically resolve: Morais et al. (2022) find that formalisation policies differ greatly between countries and often fail to deliver the legal recognition, safe conditions and fair bargaining they promise, while pickers' contribution to circular economy goals is systematically undervalued. A facility that captures the residual stream competes for material with people whose livelihoods depend on it.

Rousta et al.'s (2020) meta-analysis indicates where separation programmes should concentrate. Attitude, moral norm, subjective norm and perceived behavioural control show moderate correlations with participation, while socio-demographic factors — the most studied — show the weakest influence. Programmes designed around who residents are will underperform relative to programmes designed around what residents believe others expect and whether they believe participation is feasible.

### **Limitations**

Five limitations qualify this study. First, no verified peer-reviewed source within the review window reports Indonesian national generation, per capita generation or collection coverage, so the domestic argument proceeds from city-level studies without a national baseline. Second, no verified source quantifies waste-to-energy air emissions, so the principal environmental objection to incineration is acknowledged but not assessed here. Third, the composition evidence comes from four cities in three countries, on different analytical bases, and is indicative rather than representative. Fourth, two of the Indonesian economic sources are conference papers rather than journal articles. Fifth, no verified source quantifies the share of national recovery delivered by informal pickers, so their contribution is established qualitatively and by one city-level measurement.

## 5. CONCLUSION

Waste-to-energy is offered to rapidly urbanising cities as a solution to a problem that, on the available evidence, it is not positioned to solve first. A global inventory across 50,702 municipalities finds uncollected waste dominant in the Global South against littering in the Global North, with plastic emissions of 52.1 million tonnes annually and approximately 57 per cent of that open-burned. Material that never enters the managed system cannot be treated by a facility at the end of it, so collection coverage is the binding constraint and treatment capacity is not a substitute for it.

Composition then makes combustion conditional rather than universal. Sampled waste in one African city was 80 per cent organic with a lower heating value of 6.12 megajoules per kilogram at 25 per cent moisture; the organic fraction is both the lowest-value fuel and the fraction most readily diverted; and a calorific value of 11.99 megajoules per kilogram from an Indonesian city was determined on a dried sample and therefore overstates what a plant would receive. Composition is also not stable: organic content at one dumpsite fell from 70.5 per cent when fresh to 0.35 per cent after fifteen years, with calorific value declining alongside it.

The practical conclusion concerns order. Collection coverage, source separation, organic diversion and residual characterisation each determine the material available to the next step, so a plant sized before those four are settled has fixed its design feedstock before that feedstock is determined — and on the Indonesian evidence, a configuration that breaks even only in its sixth year of a fifteen-year life has little tolerance for being wrong. Two further considerations belong in the same decision: a minimum tonnage guarantee converts upstream success into a contractual penalty, and the residual stream a facility would capture is already the livelihood of an informal recovery sector whose contribution is undervalued and whose formalisation, on the review evidence, frequently fails to deliver what it promises. Measure the residual before committing the capacity.

## ACKNOWLEDGEMENTS

The authors thank the editorial team of Research Center Progresif for their assistance.

## DECLARATIONS

### Author contributions (CRediT)

I Wayan Aditya Yoghisvara: conceptualisation; methodology; formal analysis; writing - original draft; writing - review and editing.

### **Conflict of interest**

The authors declare that they have no competing interests.

### **Data availability**

All data supporting the findings of this study are available within the article and from the publicly accessible sources cited therein.

### **Funding**

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

### **Declaration on the use of artificial intelligence**

Claude (Anthropic) was used for language editing and for translation of the manuscript into English. The authors reviewed and verified all content, and take full responsibility for the final text. No generative tool was used for data analysis, for the interpretation of results, or for the generation of scholarly content. AI is not listed as an author.

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