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WORLD ECONOMIC FORUM

Scaling Traceability Innovation to Unlock the Value of Informal Waste Management

WHITE PAPER

NOVEMBER 2025

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Contents

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Foreword

Wesley Spindler
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How we source, trace and manage waste responsibly is central to the future of circularity, climate action and corporate responsibility. This is not just a question of how we track waste but also its accountability, human rights, environmental impact and return on investment.

If we address these priorities through emerging technologies, such as digital product passports, blockchain and AI-driven analytics, we can gain access to new, transformative solutions. This whitepaper highlights how these innovations are advancing in emerging markets today and invites collective action to accelerate the systemic change still required.

Wesley Spindler
Managing Director, Sustainability, Accenture

An effective transition to more sustainable and resilient industries cannot leave anyone behind, even when the change needed is so significant that it requires the 'leapfrogging' of intermediate and outdated models.

Early-stage innovations can support this transition, but they require collaboration, investment and trust. When society invests in ideas as a collective, economic models can surge forward, not only becoming more resilient but also positively impacting all who depend on them.

Pedro Gomez
Head, Industry Agenda, World Economic Forum

Understanding how to scale innovation often feels elusive in the moment. What succeeds in one region may falter in another, which is why diverse perspectives are essential. Traceability, in particular, thrives on cross-border exchange and depends on networks of partners coming together to test, adapt and learn.

This whitepaper is proof of the value of doing just that. It makes clear that innovation at scale is not an aspiration for the future: it is happening now, across industries and regions, powered by a diversity of perspectives and the collective will of the ecosystem to act.

John Dutton
Head, Uplink, World Economic Forum

Traceability will be a cornerstone of the transition towards a data-driven circular economy. But laying its foundations requires the courage to act together in a coordinated way. The Global Plastic Action Partnership has overseen the progress that comes when partners step up to take ownership. When their actions synchronize, it creates deep and long-lasting transformation.

This willingness to share responsibility drives change and underpins the community that created this report. In standing up together, we took another step towards responsibly sourced waste materials and uncovered new opportunities. I hope this spirit of collaboration continues to guide our efforts.

Clemence Schmid
Director, Global Plastic Action Partnership, World Economic Forum

Executive summary

Greater collaboration is key to ensuring traceability innovation can tackle the waste crisis at scale.

The world faces an escalating waste crisis, with emerging economies bearing the heaviest burden. Rapid urbanization, limited infrastructure and insufficient financing have left waste unmanaged, creating severe health, environmental and economic consequences.

In parallel, a vast but undervalued informal waste system recovers an estimated 88 million tonnes of recyclables annually, exceeding formal collection in Europe across similar categories.[1] However, this contribution remains largely invisible due to a lack of traceability and recognition.

A maturing wave of traceability innovations is transforming this landscape. Digital tools, blockchain platforms, AI analytics and emerging businesses are demonstrating that capturing verifiable material *and* labour data from the first point of informal waste collection onwards is feasible.

By making the contributions of informal waste workers visible, traceability provides a 'map' for effective policy, investment and corporate action towards solving the waste crisis. Such visibility also unlocks strategic insights that are critical for businesses currently confronting a major challenge: as many as 60% admit that lack of supply chain visibility is a significant risk-management issue.[2] Traceability that includes the informal steps of supply chains offers a compelling mix of cost efficiencies, revenue gains, brand trust-building, investor appeal and risk mitigation.

To achieve those goals, this paper presents:

- **Real-world examples** of traceability innovations active today – from AI-driven fraud detection to blockchain-anchored chain of custody systems – demonstrating technical and social viability across diverse contexts.
- **A practical evaluation framework** with 10 guiding questions to help decision-makers assess their most appropriate solutions for tracing waste into and out of the informal sector.
- **A roadmap for achieving scale**. As incremental change struggles to keep pace with the surge in waste, this roadmap explores shared digital infrastructure as a 'leapfrog idea' to accelerate transformation.

Moving towards greater scale requires improved coordination and collaboration. We call on governments, industry, innovators and civil society to collaborate in shaping the shared language and common infrastructure needed so that transparency extends to both materials and people. Without this collaboration, the essential overhaul of waste management systems will remain incomplete, unsighted to the full scope of what is required and contributing to misguided long-term investments.

Introduction

It is time to illuminate the path from fragmented informal waste collection to integrated, traceable supply chains.

The global waste crisis is most acute in emerging countries, where waste generation is growing more quickly than existing infrastructure can keep pace with. In many regions, there is a yawning gap between generation and infrastructure, with low-income countries burning or dumping an estimated 93% of waste in the environment.[3]

Within this crisis lies a mostly unseen by solution. Across emerging markets, an extensive informal waste management infrastructure is operating at remarkable scale. Estimates suggest that waste pickers recover more than 88 million tonnes of recyclables annually – a volume far exceeding the 76 million tonnes of equivalent categories collected formally across Europe.[4] For plastic, the critical role of the informal collection sector is recognized as one of eight systemic interventions central to achieving a meaningful reduction in plastic pollution.[5]

However, this contribution remains mostly unseen by policy-makers and global supply chains due to a critical gap in traceability. This invisibility perpetuates the marginalization of informal workers while preventing the integration of these recycling networks into formal value chains.

A maturing wave of traceability innovations offers the potential to bridge this gap. These solutions capture verifiable data from the first point of waste collection onwards, giving visibility of both material flows and working conditions. This data can help enable the formalization and financial inclusion of workers[6] and is an essential puzzle piece in achieving end-to-end traceability, from waste collection to recycling and the manufacture of new products.

The task now is to scale these innovations beyond a country or supply chain. The sector needs to explore the challenges and opportunities of working collaboratively as an ecosystem to share intelligence that can precipitate systems change. Because only together can we illuminate the entire system, understand where we are at and move forward with clarity.

This paper starts by examining the magnitude of the waste crisis in emerging countries and the contribution of informal workers to tackling it. We then showcase genuine examples of traceability innovations active today, sharing a practical guide to help decision-makers evaluate the best options for implementation. Finally, we outline a pathway for scale, including an opportunity to leapfrog towards systems change.

For corporate buyers seeking verified recycled content, recyclers wanting to level the playing field through transparent sourcing, policy-makers designing effective incentives and enforcement mechanisms, NGOs working on labour and human rights and investors evaluating opportunities in this emerging space, this paper offers insights into what is possible today and a roadmap for what could be achieved tomorrow. While each stakeholder brings distinct motivations, everyone committed to genuine change needs the transparency that traceability systems can provide. The question is no longer *if* informal workers should be integrated into traceability systems, but *how effectively* this integration can be achieved in a just and cost-effective way.

1 Waste management in emerging countries

Traceability innovation can unlock crucial informal capacity and help close the waste management infrastructure gap.

The most cost-effective approach to addressing the waste crisis in emerging countries is to minimize waste generation. However, while effective upstream strategies are vital, they must be accompanied by urgent action to establish robust downstream infrastructure.[7]

Amid the crisis, a vast informal infrastructure is already operating, largely unseen – new analysis makes clear just how significant this sector's contribution to tackling this issue already is. Alongside this, a number of traceability innovations are becoming available that can translate the invisible contributions of informal workers into verifiable data, helping to underpin effective investment, policy and corporate action.

1.1 The challenges waste management systems face

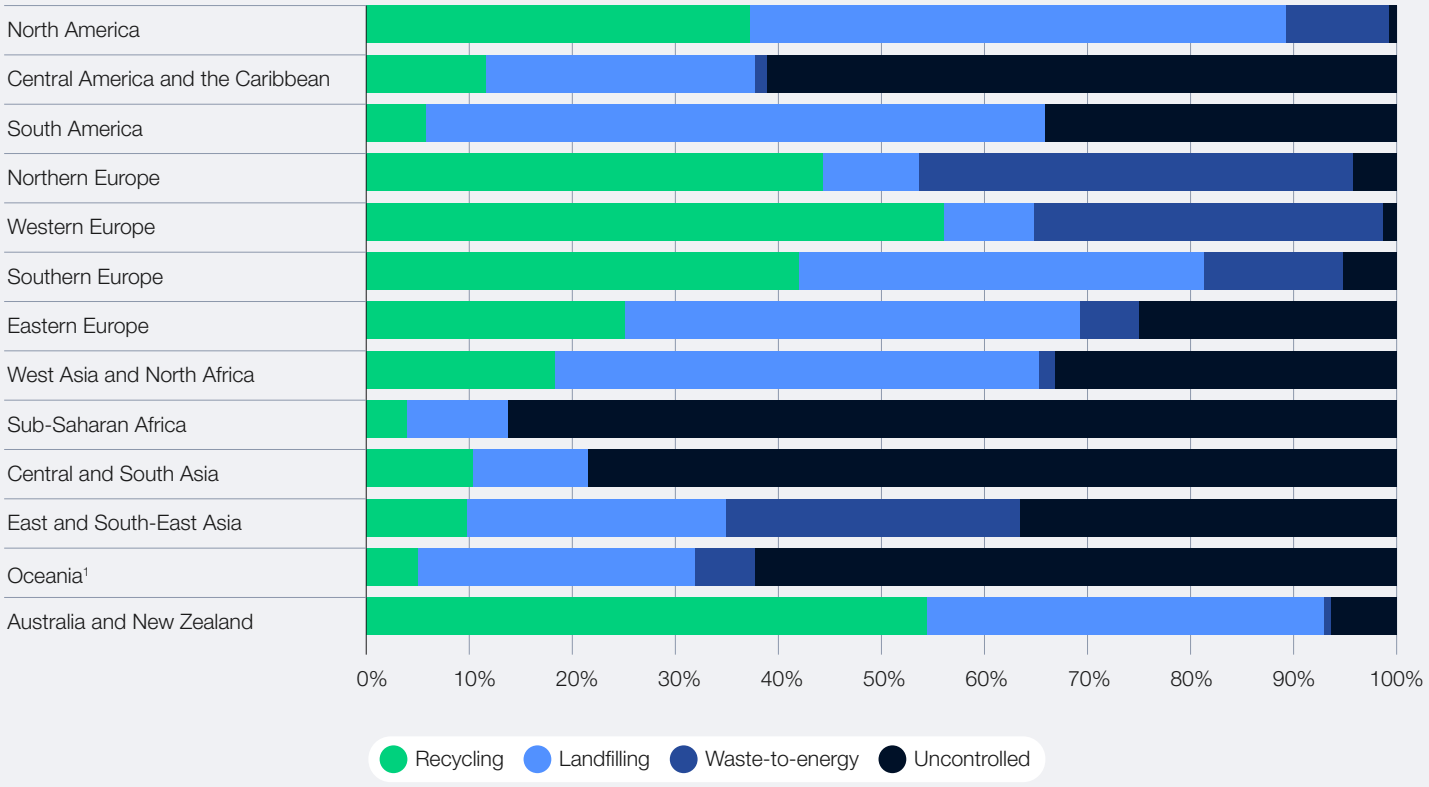
Developing comprehensive waste management systems in emerging markets is a critical infrastructure challenge for the coming decade, set to cost an estimated $680 billion.[8] Already today, between 400,000 and 1 million people die every year from diseases linked to mismanaged waste.[9] Clear connections exist between poor waste management and drinking water pollution, soil pollution, greenhouse gas emissions, air pollution, environmental degradation, biodiversity loss and more.[10] In 2020, it is estimated that the cost of these externalities to society amounted to more than $361 billion.[11] Addressing this crisis is not solely an environmental imperative, it is also a social, economic and public health necessity.

However, current financing levels fall well short of meeting this challenge. In 2021, development funding for solid waste management reached $1.8 billion,[12] and in 2024, another $1.8 billion of private investment was directed towards plastic waste solutions across Asia, Oceania, Latin America and Africa.[13] While these figures do not represent the full picture of financing flows, they do indicate the scale of the funding gap. Bridging it will require an exponential increase in financial commitments that matches the scale of the problem.[14]

In emerging markets, governments face competing priorities for resources which limit their ability to deliver essential waste management services.[15] As a result, an increasing number of countries are adopting or considering extended producer responsibility (EPR) policy frameworks that reallocate part of the financial or operational responsibility for waste management to producers. For plastic waste management, the Business Coalition for a Global Plastics Treaty reinforced this momentum, releasing a statement following the INC-5.2 negotiations in Geneva in which it reiterated the call for harmonized regulation, including EPR policies.[16]

While these policy shifts signal important progress, the situation in some regions underscores how far there is to go. As shown in Figure 1, Sub-Saharan Africa and Central and South Asia have the highest proportions of uncontrolled waste: just over 80% in Sub-Saharan Africa and just under 80% in Central and South Asia.

FIGURE 1 **Regional distribution of municipal solid waste destinations (2020)**



1. Does not include Australia or New Zealand.

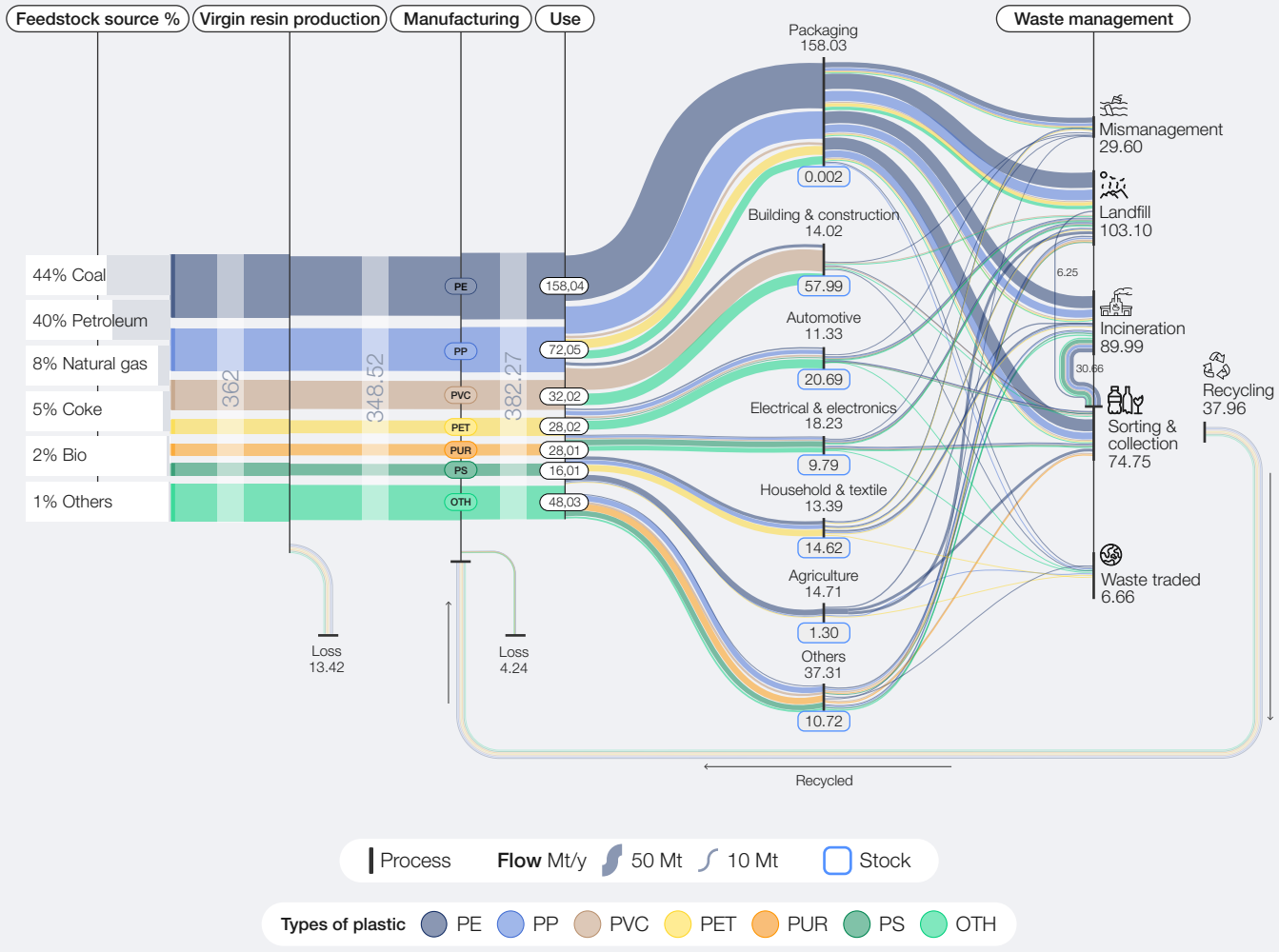
Source: United Nations Environment Programme (2024).[17]

The high proportion of uncontrolled waste in these regions indicates that waste is either not collected at all or, if collected, is openly dumped or burned at its final destination. The consequences of this mismanagement are visible and far-reaching: waste accumulates across roadsides, open fields and natural landscapes, flows into rivers, seas and oceans, and piles up near people's homes or in informal dump sites where it is eventually burned, all of which creates damaging pollution and environmental destruction.[18]

BOX 1 Plastic pollution

Within the wider global waste crisis, plastic waste is a particular concern. The graphic below illustrates the global flows of 400 million tonnes (Mt) of plastic in 2022, of which 158 Mt was used for packaging. Most of this packaging was incinerated, sent to landfill or mismanaged, ultimately ending up in the environment.

Global plastic cycles



Source: Houssini, K., Li, J., & Tan, Q. (2025).[19]

Global annual production of plastic grew from 2 Mt in 1950 to between 400[20] and 475[21] Mt in 2022. The rapid growth of plastic is fuelled by its desirable properties: lightweight, strong, highly mouldable, impermeable to liquids, resistant to physical and chemical degradation and low cost.[22]

However, some of those qualities, especially combined with poor disposal mechanisms, are also causing grave harms: health-related economic losses from plastic alone are calculated to exceed $1.5 trillion annually. These impacts fall disproportionately upon low-income and at-risk populations. The Minderoo–Monaco Commission found that current patterns of plastic production, use and disposal harm human and planetary health at every stage of the plastic lifecycle.[23]

In the absence of the structured and regulated systems run by municipalities, private companies or formally integrated cooperatives that constitute formal waste management, informal workers step in to fill the gaps. Anyone can participate, leading to a large number of decentralized actors entering the system independently. These workers operate hyper-locally, often constrained by how far they can walk, and the system organizes itself around local waste supply and demand from recyclers rather than centralized planning or investment.

Estimates suggest that, worldwide, 15 to 20 million people participate in informal waste management,[24] carrying out activities from collection and transportation to sorting and processing. While a small number work as part of a cooperative, association or community-based organization, the vast majority operate independently. Their contribution is indispensable, but daily realities are harsh: unstable and precarious earnings, lack of legal recognition, little social protection and limited access to safe working conditions.[25] Networks such as Women in Informal Employment: Globalizing and Organizing and the International Alliance of Waste Pickers – which represents more than 460,000 workers in 34 countries – are bringing these issues to global attention.

This situation underscores a paradox: informal systems are both indispensable and undervalued. To move forward, the task is not only to close financing gaps and expand formal systems but also to find ways of unlocking the value already embedded in informal infrastructure.

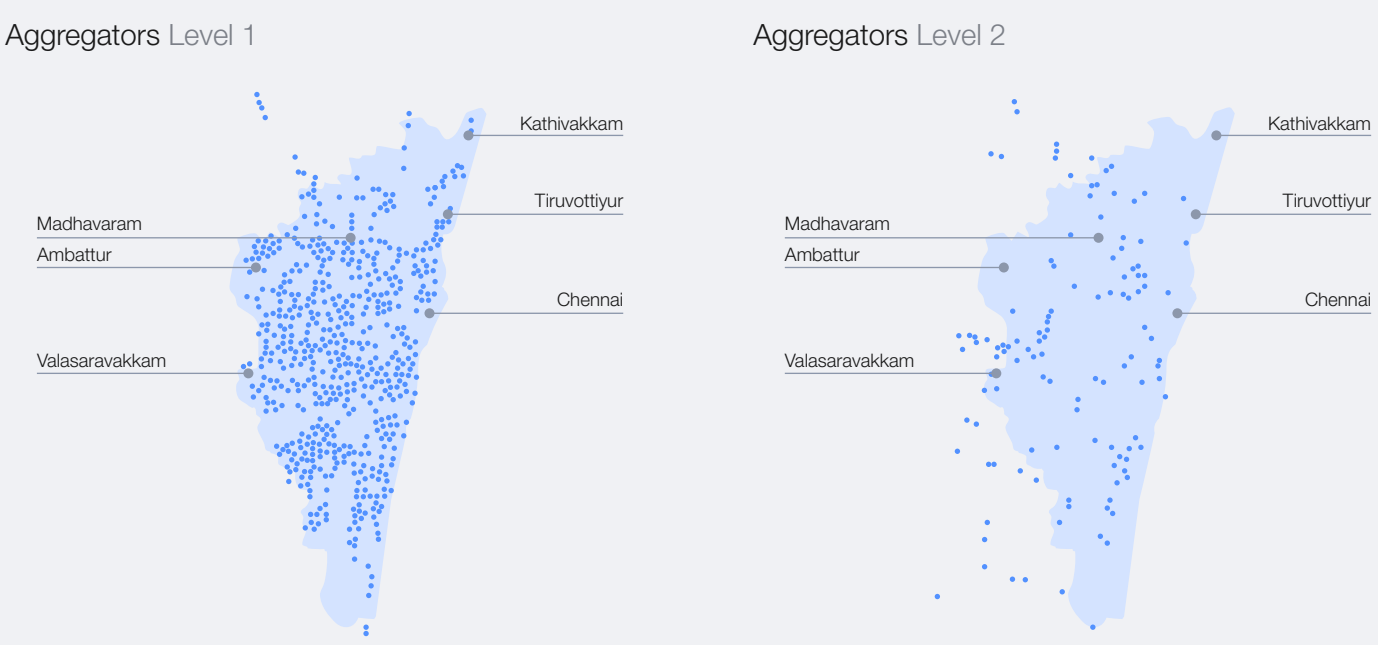
1.2 Unlocking the value of informal infrastructure

Over the last decade, data on informal waste management has increasingly become available. One indicator of this is the surge in waste management and traceability startups that emerged in the early 2010s, building their business models around digital tools and platforms that track waste flows and generating new data sets about previously invisible informal systems. As these startups secured early-stage venture capital and impact investment, they scaled their platforms and expanded their coverage. Each new user and project multiplies the amount of data collected on informal waste practices – essential as growing regulatory and corporate demands rapidly accelerate the need for granular data.

This increased body of data availability provides a clearer understanding of collection volumes by the informal sector, leading to the **estimate that waste pickers recover 15% more recyclables by volume than the whole of Europe's formal collection system (88 million tonnes versus 76 million tonnes annually across equivalent categories).**[26]

When material flows and business activities are mapped geographically, once-hidden informal infrastructure becomes visible. An illustrative example comes from Chennai, India, where Kabadiwalla Connect mapped the city's network of waste aggregators – the intermediaries who purchase, sort and consolidate recyclables collected by waste pickers before selling them on to larger processors. Their analysis revealed the structure, scale and reach of informal waste collection networks. Level one aggregators receive waste from a variety of stakeholders (including waste pickers, households and businesses), while level two aggregators consolidate materials from multiple level one aggregators, creating larger volumes before selling to processors and recyclers. Together, they handle 130,000 tonnes of materials, such as paper, plastic, glass and metal annually – equivalent to 25% of the city's waste generation.[27]

FIGURE 2 **Geographical spread of informal sectors in Chennai, India (2015)**



Source: Development Asia (2024).[28]

Similar two-layer aggregator structures have been documented in numerous scientific studies.[29] They have also been noted in multiple regions through the World Economic Forum's traceability innovation working group (see Chapter 2).

It is clear that the decentralized nature of informal waste management does not diminish its role as infrastructure; it defines it. Handling 88 million tonnes of materials annually is not a marginal activity but a large-scale service integral to the proper functioning of waste management systems.

However, the combination of informality and decentralization poses challenges to advancing waste management systems and circular supply chains at the speed and scale required to address the waste crisis, while also ensuring a just transition. Workers enter and remain in informal waste management for a variety of reasons. Many have no other viable employment options. Aligning tens of thousands of these local actors to maintain consistent quality and volumes is time-consuming and costly. Rapid reforms risk disrupting livelihoods and sparking resistance, while inaction deepens the waste crisis.[30] The informality of this workforce means the limited visibility of output quality, working conditions and volumes handled hampers effective policy-making and investment, preventing resources from reaching the workers and communities who need them most.

This complexity makes it difficult to unlock the full value of the informal waste sector: although its contribution is substantial, without mechanisms for visibility and verification, it remains persistently undervalued.

The maturing wave of traceability innovation is helping to address this. Over the past decade, startups, civil society, corporations and public institutions have developed and implemented solutions capable of capturing verifiable data from the first point of waste collection onward. Technical innovations and local experiences of implementing them make it possible to record who collected what, where and under what conditions. Crucially, this enables not only the tracking of material flows but also social and labour conditions, supporting the formalization of waste workers and extending financial inclusion.[31]

By turning invisible practices into verifiable information, these innovations create the foundation for building value. Data alone is not enough – it must be supplemented by deliberate efforts to transform – but it does ensure decisions by governments, companies and investors are grounded in reality rather than assumptions. Data provides the map that ensures the engine of policy, investment and corporate practice does not veer off course.

1.3 PCR feedstock as a lever for change

Post-consumer recycled (PCR) feedstock for plastic is an example of a waste-based material stream where scaling of traceability innovations is increasingly prized by industry. PCR feedstock refers to end-of-life consumer materials that are collected and reprocessed into raw inputs – feedstock – for new products. Because manufacturers purchase this recycled feedstock, waste gains a market value, shifting incentives from disposal to recovery.

Growing concern over plastic pollution has led to efforts to make the collection and recycling of plastic waste economically viable, increasing the focus on PCR. Both voluntary commitments and regulatory requirements have put PCR feedstock on corporate agendas:

- On the voluntary side, producers are integrating PCR to meet corporate sustainability goals, consumer expectations and participation in plastic credit schemes. Many global brands have pledged minimum recycled content in packaging.

- On the regulatory side, governments are introducing a mix of incentives and mandates to increase the adoption of PCR feedstock. These include tax incentives that make virgin material less competitive, as well as mandatory recycled content targets. The EU Packaging and Packaging Waste Regulation (PPWR) introduces a minimum percentage of recycled content that manufacturers must recover from post-consumer plastic waste,[32] while India has set some of the most ambitious and rapidly increasing PCR targets.[33]

Early market shifts are underway: in 2023, signatories of the Ellen MacArthur Foundation's Global Commitment reported an average of 14% PCR content in their plastic packaging. This marked the sixth consecutive year of growth, though it remains below the collective target of a 26% average.[34] Interviews digging into this issue highlight the low price of virgin material, coupled with fraudulent claims that virgin resin is recycled, as key factors undermining further development of recycling systems. Robust regulation is only the first step; meaningful change depends on effective enforcement.

In response, the case for traceable PCR material is strong, reinforcing its role as a lever for change in two ways. First, trusted material can help bolster waste management infrastructure in emerging countries by creating stronger economic incentives for collection, sorting and recycling. Second, it strengthens the business argument for traceability innovations that include informal workers: companies sourcing PCR at scale must be able to verify origin, quality and working conditions from the source of that material, which in emerging markets is inevitably the informal sector.

That business case extends beyond compliance. With today's complex, dispersed supply chains and opaque supplier practices, as many as 60% of businesses say that lack of visibility poses a significant risk-management issue.[35] Robust tracking of both materials and social conditions offers a compelling mix of potential cost efficiencies, revenue gains, brand trust-building, investor appeal and risk mitigation for product manufacturers. When

implemented effectively, traceability can level the playing field and protect legitimate stakeholders from unfair competition.

As recycled-content commitments and mandates continue to expand, PCR is emerging as a natural proving ground for traceability solutions at scale, demonstrating how visibility can unlock value across environmental, social and economic dimensions.

BOX 2 Corporate business case for traceability

There are several additional challenges to implementing traceability solutions in informal settings. Low digital literacy, limited trust and uneven access to technology can slow adoption and demand increased effort. Yet when viewed as a business case, especially given the current absence of empirical research or benchmark data for recycling, these costs should be weighed against the potential for broader value:

Finance and procurement efficiencies

Manual and fragmented data management processes in procurement can be costly. In 2020, a Harvard Business Review Analytic Services study found that 24% of companies fail to evaluate supplier practices effectively, with 45% citing manual processes as the main cause of incomplete data and 44% putting it down to a lack of tools and technologies to evaluate and monitor suppliers.[36]

Legal compliance and potential tax reduction

The regulatory landscape is shifting quickly. EPR schemes now span all continents, with at least 25 countries announcing recycled content targets, taxes or penalties for non-compliance.[37] Under the EU PPWR, for example, recycled content from post-consumer plastic waste must adhere to specific sustainability and traceability requirements – even if sourced in a third country.[38] Effective traceability provides the granular, verifiable data needed to prove compliance, qualify for EPR fee reductions and avoid costly penalties.

Product price premium

Consumers value brands that support recycling initiatives. Depending on product type, research by MIT Sloan suggests that supply chain transparency, especially with regards to worker treatment and social impact, can justify price premiums of up to 10%.[39] Therefore, in markets where ethical and environmental credentials influence purchasing decisions, verified traceability unlocks access to higher-margin segments.

Improved brand perception and stakeholder appeal

The responsible procurement that effective traceability enables can serve as a flagship corporate social responsibility (CSR) initiative. Research shows that effective CSR strategies strengthen a company's reputation, enhance its market value and are strongly correlated to financial performance.[40] By embedding social indicators into traceability systems, companies can credibly demonstrate their commitments, strengthen brand trust and increase their appeal to sustainability-focused investors and funds.

Strengthened social audits and reduced costs

A data-sharing ecosystem, especially one enhanced with an AI model, can provide real-time insights, foregoing the need to wait for quarterly or yearly social audits. Such high-quality, in-person audits are costly, requiring substantial time, expertise, trust and resources.[41] They also may only offer a snapshot of one moment in time. The use of digital traceability tools that capture the right data in the right way can make the process more efficient and effective, especially when results are shared. The Open Supply Hub is one such initiative aiming to create an open and accessible map of the world's production locations.

Reduced risk and reputational loss

The reputational stakes for ethical lapses are high, with CSR reporting among S&P 500 companies surging from 20% in 2011 to 90% in 2019.[42] One in four consumers report zero tolerance for unethical practices.[43] Traceability safeguards against these risks by ensuring continuous monitoring, and early detection enables verification of both material flows and social conditions.

While companies naturally evaluate investments through their own business lens, there is also a pre-competitive opportunity to pool resources, align approaches and reduce duplication. Collaborative traceability solutions can achieve scale and impact that no single actor could realize alone. Recognizing both the internal business case and the collective opportunity is essential to building resilient and inclusive systems – an idea explored further explored further in Chapter 3.

2 Traceability innovation to enable responsibly sourced waste

Paving the way for post-consumer waste to become a trusted raw material.

In a linear economy, traceability ends at the consumer. In a circular economy, it continues beyond that point, tracking materials through post-consumer stages. Thanks to a decade of traceability innovation, post-consumer waste handled in informal contexts is beginning to be recognized as a reliable input. This chapter highlights new material traceability developments that cover the informal sector, showcases established innovations and introduces an evaluation framework to help decision-makers select the solution that best helps them obtain responsibly sourced waste.

Responsibly sourced waste:

While this term has no universal definition, in the context of this report, it refers to post-consumer waste materials of legitimate origin and with verifiable transparency across both material flows and ethical labour practices.

2.1 New developments in traceability innovation

While the concept of traceability has existed for decades, its focus and drivers continue to evolve. Food was one of the first sectors where traceability took off, led by legislation on food safety and deforestation. Similarly, most development tends to take place in highly regulated sectors, such as pharmaceuticals, automotive and aerospace.[44]

The mounting urgency of the waste crisis and its associated policy-making has triggered a surge in traceability innovation, producing digital tools that map, verify and track waste flows and related social data on fair labour practices among informal workers. These solutions vary in technological implementation, while some are combined with new business models and process innovations. All fall under the umbrella of social innovation, where creating value for society is the key purpose. Over the past decade, these tools have shown that it is both technically and economically feasible to capture granular data from decentralized, informal waste management networks in all regions of the world.

What is different now from before is a convergence of trends reinforcing each other. As with all innovation scaling, timing is everything.

- **Technology:** Digital payment systems, blockchain platforms and AI-driven analytics are no longer abstract concepts. They are being tested and tailored to the realities of informal waste management. The following chapter highlights some examples.
- **Capacity:** Decades of NGO work have created a foundation of community engagement with informal workers and tested models for adequate implementation for these technologies. The Responsible Sourcing Initiative is one example of a programme that is harmonizing different frameworks and implementing accordingly.
- **Policy:** During the last decade, a commitment to a just transition has been part of both international and national climate law frameworks.[45] During negotiations for the planned global plastics treaty, waste pickers entered the global policy arena, complementing advocacy at national and regional scales.[46] While the treaty negotiations continue, national frameworks in India, Brazil, the Philippines, Malaysia, Colombia, Chile, South Africa and Uruguay already recognize the role of the informal sector.[47] These frameworks are far from perfect – implementation gaps remain, and commitments are not always matched with the necessary resources or enforcement – but the shift is undeniable. In parallel, regulators are beginning to demand material traceability back to its source, which, by necessity, reveals the importance of informal workers in emerging markets.
- **Corporate accountability:** Research from 2024, based on the 5,800 largest companies, finds that 42% now utilize double materiality assessments in their reporting, meaning they assess their impacts on society and the environment and how this affects financial performance.[48] That accountability is also passed on to the partners they work with, as corporates seek visibility of where their money goes and what impact it delivers, creating demand for more transparent, data-backed systems.
- **Public-sector transparency:** Governments, too, are expected to demonstrate how funds for waste management are being used effectively and inclusively. A 2024 analysis by the World Bank on results-based financing (RBF) approaches in the waste management sector identifies opportunities for upscaling, tying fund disbursement to pre-agreed outcomes or performance targets.[49] For RBF to succeed, reliable and transparent data on waste management is essential.
- **Consumer expectations:** Consumers are becoming more conscious of sustainability, including waste, pushing brands and policy-makers toward greater accountability. One in four consumers report zero tolerance for unethical practices.[50]

2.2 Real-world applications

The true value of these innovations is best understood through live examples. This section highlights particularly innovative aspects of traceability solutions and describes the relevant market. Later in the chapter, a framework for evaluating traceability solutions is introduced, after which it may be helpful to return to these cases, as we apply it here.

CLEANHUB

AI auditing of unusual data patterns to help detect fraud

Tech innovation

Platform player archetype

Cleanhub sells verified plastic credits to brands and uses the revenue to fund plastic collection. Operating in India, Indonesia, Guatemala and Tanzania. www.cleanhub.com

Cleanhub has developed an 'AI auditor' – a system that automatically analyses the large amounts of data submitted by waste collectors and processors and looks for unusual patterns that may point to fraud. In one example, it detected a problem in a Tanzanian project. The AI auditor noticed that photos of plastic bales were uploaded at unusual frequency and noted identical dust patterns in the photographs. This revealed an attempt to report the same material multiple times. Another example of fraud detection happened in Indonesia where the AI auditor detected an unusual increase in volume that did not match regional patterns. A waste aggregator was purchasing new packaging while reselling it as 'collected waste'.

These examples show how AI can flag potential fraud in real time across different types of data, such as photos, weight receipts and invoices. Compared to traditional audits, which often require sending someone onsite to manually review paperwork or spreadsheets, AI greatly increases confidence in the accuracy of reported waste volumes.

GREEN MINING

Direct payments maximizing income for waste pickers

Business model innovation

Platform player & vertical integrator archetype

Green Mining sells factory-price stations to corporate partners and operates them as an aggregator. Operating in Brazil. www.greenmining.com.br

A factory-price station (FPS) is where waste pickers drop off materials they have collected. However, the business model operates differently to traditional aggregators. In conventional systems, waste pickers sell materials to aggregators at low prices. These aggregators then mark up the prices before selling to recyclers. This means waste pickers receive only a fraction of the material's true value.

At factory-price stations, waste pickers receive the full value. This is possible because corporate partners cover all the station's infrastructure costs (such as buildings, equipment, staff and logistics) as part of their sustainability or EPR commitments.

To ensure impact for corporate partners is realized, material and social data is supported by a proprietary platform using blockchain, georeferenced data and photographic records, guaranteeing full traceability and compliance with labour and environmental standards.

PLASTIC BANK

Experience-based interest-free loans for waste pickers

Social and tech innovation

Platform player archetype

Plastic Bank sells both plastic credits and recycled feedstock, using the revenue to pay its collection and recycling partners. Operating in Canada, Indonesia, Philippines, Egypt, Brazil, Thailand and Cameroon. www.plasticbank.com

A distinctive feature of Plastic Bank's model is the way it integrates financial inclusion. Waste pickers are paid above market rates through direct digital wallet payments. This creates proof of social impact while building a credit history and user score that unlocks interest-free token advances and financial services that would otherwise be inaccessible to informal workers.

ECO2VERITAS

Turning sustainability claims into real-time verifiable proof

Tech innovation

Traceability software archetype

eco$_2$Veritas sells a traceability platform that turns any type of evidence - photos, documents or IoT data - into verifiable digital records for compliance, certification and sustainability claims. Operating in Latin America and Europe. www.eco2veritas.com

eco$_2$Veritas enables collectors, recyclers and waste managers to automatically track and certify the collection, processing and recovery of post-consumer waste. Instead of relying on occasional sampling, it uses an AI engine that can process virtually any type of evidence – from photos of bales and scanned written forms to weighbridge receipts, transport logs and IoT data – and turn it into structured, validated information in real time.

All data is then stored on a blockchain ledger, making the process secure, tamper-proof and auditable. The system also automates mass-balance checks and uses built-in fraud detection to flag suspicious or inconsistent entries.

BANQU

Correlating working times with school attendance to detect child labour

Social innovation

Traceability software archetype

Banqu sells traceability software – that includes data collection from informal workers – to corporations and NGOs. Operating in 60 countries across the world. www.banqu.co

Banqu is not just checking the age of waste pickers (a standard compliance process) but enhancing the monitoring method by correlating working times and volumes with school attendance. This changes the detection of child labour from a single-variable check (age) to a more sophisticated, data-driven correlation across different indicators.

GRIYA LUHU

Traceability from local waste banks in rural areas

Social innovation

Traceability software archetype

Griya Luhu sells traceability software to digitalize waste aggregators' administration and management. Operating in Indonesia. www.griyaluhu.org

Waste banks are community-driven initiatives in Indonesia that promote at-source waste segregation and ensure materials are transported to legitimate destinations, such as recyclers. However, conventional operations remain largely manual, labour-intensive and time-consuming, making it difficult to achieve a return on investment to cover operational costs.

The Griya Luhu app aims to digitalize this system. Through the mobile app, waste collectors can easily record materials from the community, providing full traceability from collection to aggregation. This is particularly impactful in rural areas, which are among the largest sources of waste pollution in Indonesia. The app also features an educational rating system to measure community performance in waste segregation and allows households to track their balances in real time based on the materials they sell.

RIVERRECYCLE

Blended finance building circular economies along rivers

Business model innovation

Vertical integrator archetype

RiverRecycle sells circular economy projects that remove low-value plastic from rivers and turn it into recycled products. They package these projects into portfolios that are attractive and de-risked for impact investors. Operating in multiple countries across Asia and Africa. www.riverrecycle.com

Plastic waste in rivers is nobody's responsibility and much of it is low-value materials that are hard to recycle. Yet, if we want to be truly responsible, we must also recover these plastics that have no immediate market value. RiverRecycle creates a business model where none existed before.

The company combines river-cleaning services and small-scale recycling to recover and process low-value plastics, turning them into marketable products. These projects are financed by private foundations or governmental programmes. To make participation simple and scalable, RiverRecycle also offers an intermediate financing entity that channels contributions into multiple river-cleaning projects, with transparent reporting and full value-chain traceability.

Each project is backed by offtake agreements for recycled products, ensuring stable demand. As more projects are bundled together into a portfolio, the scale and de-risking make them attractive for impact investors and development banks. This blended finance approach enables long-term circular economy solutions and actively reduces plastic pollution in rivers worldwide.

SEVEN CLEAN SEAS

Linking plastic recovery with marine-plastic pollution monitoring

Business model innovation

Vertical integrator archetype

Seven Clean Seas sells plastic credits to businesses and uses the revenue to formally employ waste collectors and build infrastructure for collecting and recycling waste. Operating in Indonesia, Thailand, Singapore and the United Kingdom. www.sevencleanseas.com

At the heart of Seven Clean Seas' model is Periscope, a digital platform that tracks, verifies and communicates the outcomes of plastic recovery projects in real time. Unlike many providers, Seven Clean Seas makes this data publicly available, ensuring that impact information serves not only clients but also the wider good. Periscope can be used to monitor marine plastic trends, guide resource allocation and inform education programmes and research, while also providing organizations with audited certificates and verifiable data for sustainability reporting.

By opening up its data, Seven Clean Seas strengthens accountability, supports credible governance and advances collective efforts toward sustainable waste management.

MR. GREEN AFRICA

Empowering wastepreneurs in a way that works for them

Social Innovation

Vertical integrator archetype

Mr. Green Africa sells auditable, responsibly sourced PCR feedstock to consumer brands. Operating in Kenya. *www.mrgreenafrica.com*

Africa's first B-Corp in the recycling sector, Mr. Green Africa integrates the plastics value chain – from collection and aggregation to recycling – through owned facilities. To increase scale, it also uses a franchise model for aggregators.

Its technology-driven collection model connects informal waste workers, micro-entrepreneurs and consumers into a formalized system. A proprietary software platform provides granular, end-to-end data on both social and material impacts, ensuring traceability for brand owners who buy the recycled pellets produced. Prices are negotiated directly with brands, creating fairer market dynamics.

Waste pickers are paid via cash or mobile money and rewarded with 'green points' that they can put towards additional benefits – not just safety equipment but also essentials such as food and utilities. Meals are provided on specific days, helping to create community and trust over a shared meal.

AMBIPAR

A social franchise for auditable post-consumer recycled feedstock

Process innovation

Ecosystem orchestrator archetype

Ambipar sells auditable traceability and social safeguards for responsibly sourced post-consumer recycled feedstock. Operating in Brazil. *www.ambipar.com*

Ambipar has developed an operating model for early-chain reverse logistics, helping cooperative sorting and recycling hubs to organize professionally. Participants receive a free standardized method, toolkit, training, governance support, market access pathways and implementation support. Project finance covers investments into buildings and machinery where applicable. As operations mature, units become financially self sustaining.

There is no fixed sell through obligation for cooperatives. Market access is enabled and diversified through standardized quality and custody documentation. Where offtake agreements exist, they are offered on a case-by-case and time-bound basis. Field results using this approach indicate significant increases in income, higher quality inputs with lower reject rates and end-to-end custody documentation that enables mass balance audits. Field tests in Brazil were accelerated through collaboration with Dow, which helped prove the core thesis and the business case.

2.3 A practical guide to choosing innovations for decision-makers

The traceability innovations discussed in this paper all seek to enable waste to be responsibly sourced, but they do so through different business models. For decision-makers considering which solution to implement, understanding the differences is important. The choice of business model determines how value is created, what incentives exist for participation and how a solution can scale. This section introduces the main types of business models in this space and offers guiding questions to help evaluate which solution best fits specific needs.

TABLE 1 **Our analysis revealed three groups of business models:**

Business model archetypes	Core benefits	Limitations
Traceability software-as-a-service Sell traceability software	Transparency of social and material data; can scale with current suppliers	Adoption barriers in fragmented sectors, especially without explicit incentives
Marketplace model Sell recycled, traceable material from others through a platform	Market access for buyers and suppliers; aggregation of supply; transparency of social and material data	Ensuring quality and consistency of supply across network; balancing trust between buyers and suppliers
Vertical integrated production model Sell traceable, recycled material from own recycling plants and/or aggregators	End-to-end control creates more reliable supply; transparency of social and material data	High capital intensity; potential exclusion of waste workers if not structured inclusively

These business model archetypes provide a simple way to map the landscape. No model is inherently better; choice depends entirely on the specific need.

The following 10 questions identify the strategic trade-offs between archetypes and provide a basis for evaluating which solution aligns with the prevailing priorities. These questions are not exhaustive; more may be required depending on the specific context and priority.

Define the position in the supply chain

1. **Where is the solution active in the informal waste management chain?**
   Understanding where a solution is positioned in the chain – from waste picking and aggregation to transportation and recycling – helps clarify its role and reach. This matters because it indicates the types of stakeholders the solution interacts with. For example, a solution focused on waste picking may directly improve livelihoods and safety conditions for pickers, while one targeting recycling could influence broader market dynamics.

2. **How many aggregation steps occur between collection and recycling?**
   The number of handovers between the first aggregator and the recycler indicates efficiency and complexity. Most systems involve two levels of aggregation, though innovative models can reduce this to one. If extra steps exist in addition to the standard two-aggregator model, it is important to understand the value that each additional layer brings, as they will likely also increase costs.

3. **What materials are handled in each step?**
   Even if only one specific material is targeted, it is useful to know whether the system handles only that stream or multiple others. A single-material focus can denote stronger expertise and simpler processes. Diversification of material spreads market risk (e.g., price drops in one material) but increases operational complexity in sorting, maintaining quality and traceability.

Clarify the business model and level of integration

4. **At which steps of the chain are the relevant services or products sold?**
   Although this seems like an obvious question, solutions in this space are often pitched in generic language aimed at “solving the problem of responsibly sourced waste.” Decision-makers need to unpack who is paying and for what to assess alignment with their procurement and partnership needs. Some only sell traceability software, while others combine it with material sales.

5. **At which steps of the chain are the owned facilities?**
   For those who sell materials, ownership of infrastructure (aggregation centres, processing

facilities, recycling plants) reveals the degree of vertical integration. Some models are asset light, relying on partners, while others are asset heavy, building resilience and control. This choice has implications for scalability, capital requirements and potentially the reliability of supply. For example, an asset-light model may enable faster expansion with lower upfront investment but can increase dependency on partners, whereas an asset-heavy approach demands more capital but provides greater control and stability over operations.

Understand the supply side and connection to waste pickers

6. **Who supplies waste to the first aggregator?**
   Waste can come from individual waste pickers, households, small businesses or community collection systems. If the ambition is to reduce overall waste leakage, a broad supplier base may be more effective. If the ambition is to improve the livelihoods of waste pickers, it is crucial that they are directly involved.

7. **How and when is the waste picker paid?**
   Payment models directly affect the livelihoods, inclusion and financial resilience of waste pickers. Cash is harder to trace is but is still common in some regions. Digital payments increase traceability but require infrastructure and acceptance that may not always be present. Understanding when payments are made is important for ensuring income security and assessing whether partners can work on income stability together.

8. **Are there other incentives for the waste pickers, and does that convince them to register?**
   Critical to responsible sourcing is the registration and visibility of informal waste workers. Without this, transparency remains limited to the material itself, while the conditions and rights of those who collect it remain invisible. The question is what motivates waste pickers to participate in such registration. Some argue that a higher price for materials is sufficient, while others emphasize access to education, healthcare, safety or income stability as equally important drivers. It is essential to understand the choices any partners have made: which incentives they prioritize, why they have done so and how they align with the real needs of waste pickers in the region. Just as important is asking whether partners sought the perspectives of waste pickers before making their decisions or whether they simply assumed what was best for them.

Assess external conditions and enablers

9. **Any crucial elements that need to be in place before starting work?**
   This could include policy support, datasets or trusted local partners. Solutions often depend on certain preconditions, both software and infrastructure. It is important to understand whether the company creates these conditions themselves or whether they expect to receive support. For long-term partnerships, it is essential to assess whether the solution aligns with regional EPR policies and includes a strategy for adapting to regulatory changes.

Evaluate credibility and impact

10. **Which material and labour-practice data points should be captured, and can they be verified?**
    Traceability is only as strong as the integrity of the data behind it. Therefore, it is vital to understand what material data is captured and what labour and social data is tracked. Equally important is knowing how this data is verified: whether it relies on self-reporting, audits, third-party certification or the use of digital tools such as blockchain, IoT or AI audits. Together, these elements enable an assessment of whether a solution's traceability claims are truly credible and comparable and whether they meet the necessary requirements for compliance, transparency and impact reporting.

These guiding questions most powerfully compare different solutions when they are turned into an evaluation matrix – a structured tool for systematically assessing and comparing options. The format is straightforward:

- Rows (horizontal) represent the partners being evaluated
- Columns (vertical) represent the evaluation criteria chosen based on the defined priorities
- Cells are filled with scores that reflect the performance of each option

The criteria for comparison should be chosen based on context, with the ten questions serving as inspiration. Each criteria needs a clear definition and scoring system. For example, for a scale from one to five, it is important to define what each number means. **Depending on the defined priorities, the interpretation of high and low scores will differ**. The key is to understand and articulate the priorities so that the scoring reflects what is most relevant.

Illustrative example

A company procuring recycled materials may set criteria across both social and operational dimensions. Social priorities could include the involvement of informal waste workers and mechanisms such as the ability to provide loans.

Operational priorities may focus on ensuring consistent material quality through end-to-end control, as well as the desire to scale a chosen solution across existing suppliers.

Criteria	Scoring example
Provides loans to waste pickers	0 Does not provide loans 3 Provides loans but at interest 5 Provides interest-free loans

This same approach can be expanded across multiple criteria to build a complete picture. The definition and weighting of these criteria should reflect specific stakeholder priorities, making the scoring process subjective and dependent on the particular context. For example, if long-term scalability across geographies is a strategic business priority, include criteria that assess whether the model depends on unique local conditions, as well as how it aligns with current and anticipated EPR policies.

Criteria	Traceability software provider X	Platform player Y	Vertical integrator company Z
Provides loans to waste pickers	5	0	3
Offers end-to-end control on material quality	1	3	5
Can scale to current suppliers	5	3	1
Total	11	6	9

In addition to scoring, an evaluation matrix can also include weighting of criteria to ensure that the most important ones carry the greatest influence on the overall result. Weighting also helps different stakeholders align around shared decisions. For example, procurement teams may emphasize cost efficiency, while CSR teams may give greater weight to inclusion and social safeguards. By scoring and comparing solutions in this way, decision-makers can move from qualitative and subjective assessments to more structured, data-informed choices.

3 Looking ahead: achieving scale, fast

Now is the moment to scale a ‘leapfrog idea’ that builds a shared digital infrastructure.

The wave of traceability innovations that enables responsibly sourced waste has helped reveal more about the materials recovered and the people who recover them. One of the ways these solutions demonstrate technical viability and social impact is by including informal workers' data in the traceability of PCR materials, waste collection and recovery.

This innovation began a decade ago and has since been piloted successfully around the world. However, because these initiatives emerged in parallel, multiple platforms now operate with different data standards and limited interoperability – a natural outcome of growth in the pre-standardization phase.

Many stakeholders hold lots of data, but its fragmentation limits the scaling of impact. Individual platforms may track thousands of tonnes of materials and hundreds of workers, but insights that could transform entire regional waste systems remain siloed. Global corporations cannot easily verify the social and environmental credentials of their supply chains across different collection networks. Policy-makers lack integrated data to design effective incentives or regulation. Investors cannot assess the true scale and impact potential of informal waste systems. Most critically, the collective intelligence that could emerge from connecting these data streams – to reveal optimal collection methods, identify scaling opportunities and demonstrate system-wide impact – remains unrealized and often duplicates costs as each stakeholder tries to build their own dataset.

Unlocking those opportunities in the next phase of scale requires four interdependent enablers: more data, cross-industry collaboration, data-sharing enabling technologies and standards that create a shared language. Specifically, the following steps are crucial:

1 Expand proven traceability and collaboration models

Proven technologies and operational models that integrate informal waste workers into waste management systems – such as those identified in Chapter 2 – should be prioritized for investment and expansion. These solutions must uphold human rights and incorporate traceability mechanisms that capture both the material and the conditions of the workers involved, adapted to local contexts and aligned with EPR policies in each geography.

Effective collaboration requires long-term capability building (across areas such as digital skills and technology use) and solutions that incentivize informal workers to act as data providers while ensuring they receive direct benefits through improved income, working conditions and formalization pathways. Data safeguards must establish privacy protections and data-ownership rights from the outset.

Empirical data must be captured from the start and made available for further analysis of the business case (individual and collective traceability intelligence), the case that proves data sharing is technologically possible and the case for impact with positive social outcomes.

2 Define and adopt standards

Credible and consistent traceability requires clear standards that address both material flows and social indicators. It is vital to harmonize existing responsible sourcing definitions and frameworks for uniform evaluation and verification.

One example where the plastics industry is focusing on harmonizing social frameworks is the Circulate Initiative's Harmonized Responsible Sourcing Framework. The framework is being put to the test through implementation with multiple partners on the ground.

Well-defined standards (such as ISO 59014) and consistent frameworks help businesses verify material authenticity, enable supply chain transparency, foster trust and address human rights risks. The goal is not another standard but finding agreement for widespread implementation. To do this, it is recommended to start by transparently choosing and communicating a standard within the target ecosystem, while also staying up to date or collaborating with collective initiatives.

3 Build a multiparty tool for data sharing across the value chain for material traceability and social indicators

Effective traceability depends on a collaborative data ecosystem that connects all actors. However, many stakeholders remain reluctant to share data due to concerns about confidentiality, cost, liability and risk exposure, trust and governance. Acknowledging these barriers is a critical part of designing systems that enable collaboration while respecting boundaries. Instead of seeing these concerns as obstacles, they can be reframed as design parameters for innovative solutions.

Analysis of the design and implementation parameters of a multiparty tool requires a careful assessment of the realities of local waste management infrastructure and collaboration models. Modular data standards for material flows and social indicators must be incorporated wherever possible. Best practice from other industries, such as automotive, food and energy, should inform the design, ensuring any lessons are transferred effectively. Above all, requirements

should be defined by what it makes sense to trace and the outcomes being targeted. Sharing data from the point of collection by informal workers through to the finished product is the end goal, with a phased approach taken along the way.

Here, it may be possible to envision a 'leapfrog idea' – one that skips over intermediate steps, jumping directly to a more advanced solution. For example, instead of building yet another proprietary platform controlled by a single entity, there is an opportunity to explore the potential of a shared digital infrastructure into which existing traceability tools can be plugged, creating a kind of digital public common. This is like the shift from a private toll road to a public highway: open, modular and equitable from the start. From a starting point such as this, it will be possible to not only scale responsibly sourced waste but also guide smarter investment in physical waste systems, ensuring resources flow to where they will have the greatest impact. By embedding openness and interoperability from the outset, more stakeholders can connect, share and build on each other's efforts without costly barriers or duplication. This accelerates adoption and creates stronger network effects – a phenomenon where the value of a system increases as more participants join – to leapfrog over systems that only enable incremental change.

Leapfrogging is not only recommended but necessary because the window for incremental change is closing. Every year, the world produces over 2 billion tonnes of municipal waste – enough to circle the Earth 25 times if packed into lined-up shipping containers. This output is projected to surge 73% by 2050.[51] For plastic alone, if business as usual persists, forecasts predict that 50 kg of plastic waste will enter the ocean for every metre of shoreline in 2040.[52]

As such, building a multiparty data-sharing tool is not just a technical exercise. It is a once-in-a-generation opportunity to redefine how value chains operate and who they serve. By transforming today's concerns into tomorrow's design principles, we can create a digital ecosystem that empowers every actor, from informal workers to global brands.

If we act with urgency and imagination, we can accelerate the shift to a circular economy, enhance living standards and human wellbeing, and positively impact the triple planetary crisis of climate change, pollution and biodiversity loss.

Success depends on maintaining trust, transparency and equitable participation throughout this journey, ensuring that as systems scale, they continue to serve the interests of all legitimate stakeholders, including the informal workers whose vital contributions support all of us.

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Acknowledgements

The authors would like to thank all of the organizations and experts who attended discussions and provided inputs for this report, with special acknowledgement to those mentioned below. The report does not necessarily reflect the views of these individuals and/or their organizations. Expert advice is purely consultative in nature and does not imply any association with the takeaways or conclusions presented within this paper.

Abiplast

Ambipar

Avery Dennison

Banqu

BD Waste

Bext 360

CEIP Africa

Circularise

Circulate Capital

Cleanhub

GIVO

Greenplat

Griya Luhu

Jord Tech

Kabadiwalla Connect

Kunaal Patawari Family Holding

Plastic Bank

Rekosistem

River Recycle

Sahaas Zero Waste

Seven Clean Seas

Stride Ventures

Tearfund

The Circulate Initiative

Tontoton

Tradeverifyd

TÜV SÜD

University of Johannesburg

Verra

WIEGO

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