

# Waste, Reimagined:

## Practical Guidance *for* Digitalizing Waste Management



May 2026

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# Waste, Reimagined: Practical Guidance *for* Digitalizing Waste Management

**Cuidem Barcelona Residus**

**APROPA EL CLAUER**  
Utilitzar l'App a l'arribada al container i a l'hora de tancar-lo.

Residus reciclables (enverds)	Enverds
Tapes de vidre	Residus de fusta
Residus de plàstic i textils	Residus negres

**Cuidem Barcelona Residus**

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# Acronyms

<b>AI</b>	Artificial Intelligence
<b>DRS</b>	Deposit Return Scheme
<b>ERP</b>	Enterprise Resource Planning
<b>EU</b>	European Union
<b>GIS</b>	Geographic Information System
<b>GPS</b>	Global Positioning System
<b>GPU</b>	Graphics Processing Unit
<b>IDB</b>	Inter-American Development Bank
<b>IFC</b>	International Finance Corporation
<b>IoT</b>	Internet of Things
<b>KPI</b>	Key Performance Indicator
<b>MSW</b>	Municipal Solid Waste
<b>NFC</b>	Near Field Communication
<b>NIR</b>	Near-Infrared (sensor technology)
<b>OPEX</b>	Operating Expenditure
<b>PAYT</b>	Pay-As-You-Throw
<b>QR</b>	Quick Response code
<b>RFID</b>	Radio-Frequency Identification
<b>RVM</b>	Reverse Vending Machine
<b>SCADA</b>	Supervisory Control and Data Acquisition
<b>SGDS</b>	Société de Gestion des Déchets et de la Salubrité
<b>SMS</b>	Short Message Service
<b>UK</b>	United Kingdom
<b>UNEP</b>	United Nations Environment Program
<b>USA</b>	United States of America

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# Executive Summary

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**Today, municipalities and waste management companies around the world are exploring the use of digital tools as a way to strengthen planning and governance, improve service reliability, reduce operating costs, and build circular-economy practices. These tools also enable measurement and accountability, by generating more reliable data. However, many do not have clear guidance on identifying the appropriate tools to address specific issues, costs and benefits, or the conditions needed for successful deployment.**

This report aims to respond to such gaps. Through step-by-step guidance and real-world examples, the report helps align operational and digital staff, building knowledge and understanding on ways to unlock the benefits of digital technologies—benefits that can help make the case to leaders and decision makers to commit to investment.

The report identifies long-standing waste management challenges, such as poor data collection, disengaged households and businesses, inefficient use of waste infrastructure, and weak links across the waste value chain. And it shows how digital tools address these issues in a cost-effective and scalable way, to strengthen planning, governance, and service delivery.

THE COSTS OF INACTION ARE SIGNIFICANT:



**\$361B**

annually in global health and environmental impacts from uncollected waste and disposal through open dumping and burning.

Findings from the case studies reveal that digital waste solutions deliver the greatest impact when integrated with broader service delivery and governance reforms, regardless of whether a country is high-, middle-, or low-income. Across all income contexts, strong results were driven by improved system visibility; aligned incentives for households, businesses, and waste companies; and reduced uncertainty for planning and investment. Interoperability, clear data governance, phased implementation, and sustained citizen and customer engagement, along with the ability to demonstrate returns from pilots and phased investments, are all critical enablers, including in resource-constrained settings.

The report:



**Highlights market-ready digital tools** and assesses their maturity, performance, and cost-benefits.



**Matches solutions to needs and guides implementation** by providing a strategic and operational framework.



**Demonstrates tangible benefits** drawn from real-world examples and city case studies.

The report concludes with insights for municipalities and waste management companies on how to optimize their digitalization initiatives, including:



**Enabling conditions matter as much as technology:** Successful deployment depends on governance reform, stakeholder engagement, and strong data management. Institutional capacity, sound financial planning, and phased implementation are critical to avoid fragmentation and ensure interoperability.



**Engagement of citizens and businesses drives system performance:** Digital tools are most effective when paired with behavior change initiatives targeting both households and commercial waste generators. Information tools, incentives, and feedback mechanisms increase participation in source separation, improve compliance, and raise material quality, reducing contamination and costs across the system.



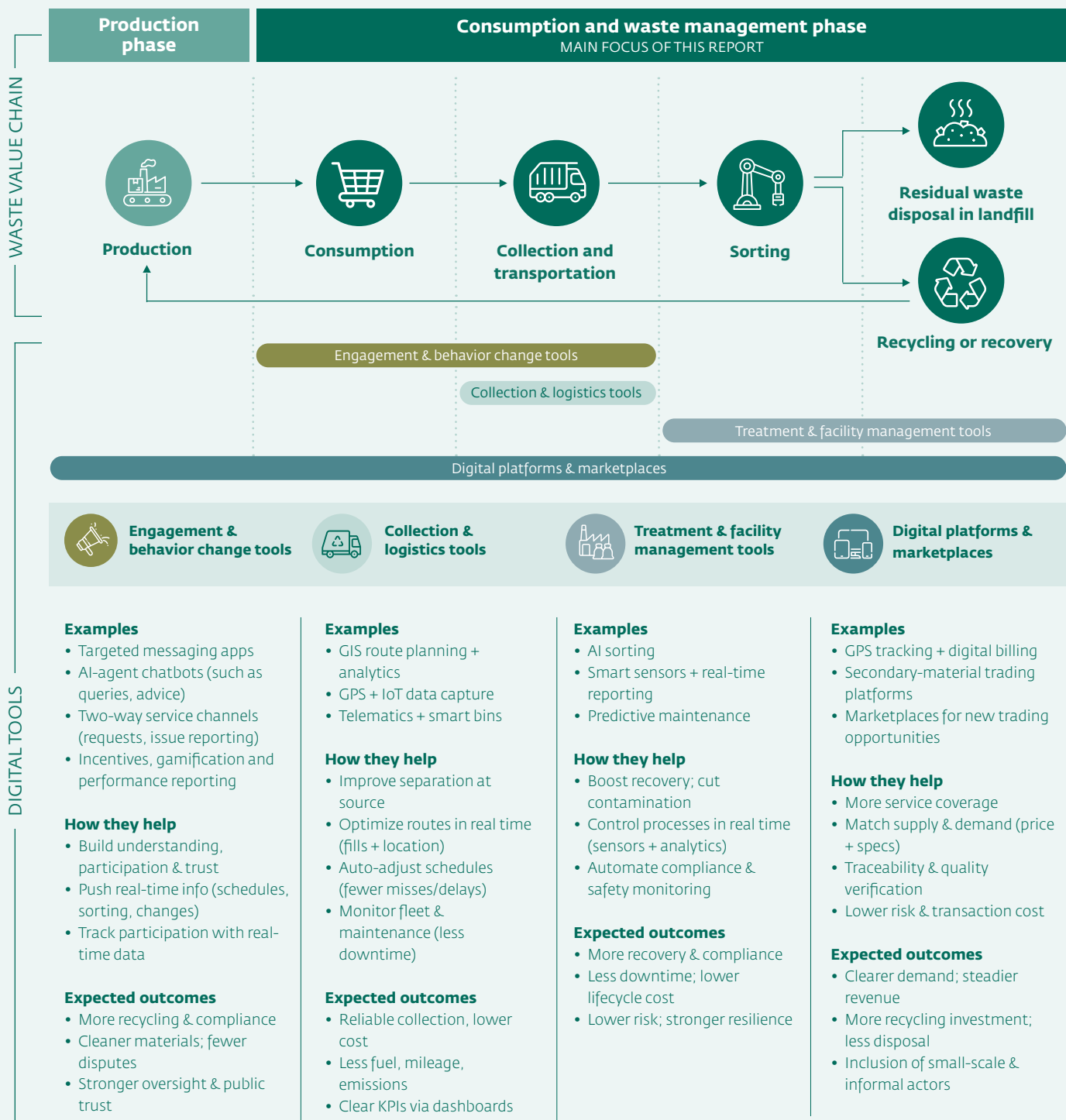
**Digitalization enables circular waste systems:** Digital solutions improve operational efficiency, reduce costs, and strengthen compliance, while supporting circular economy objectives such as higher material recovery and emissions reduction. They enable data-driven decision-making and greater transparency across the waste value chain.



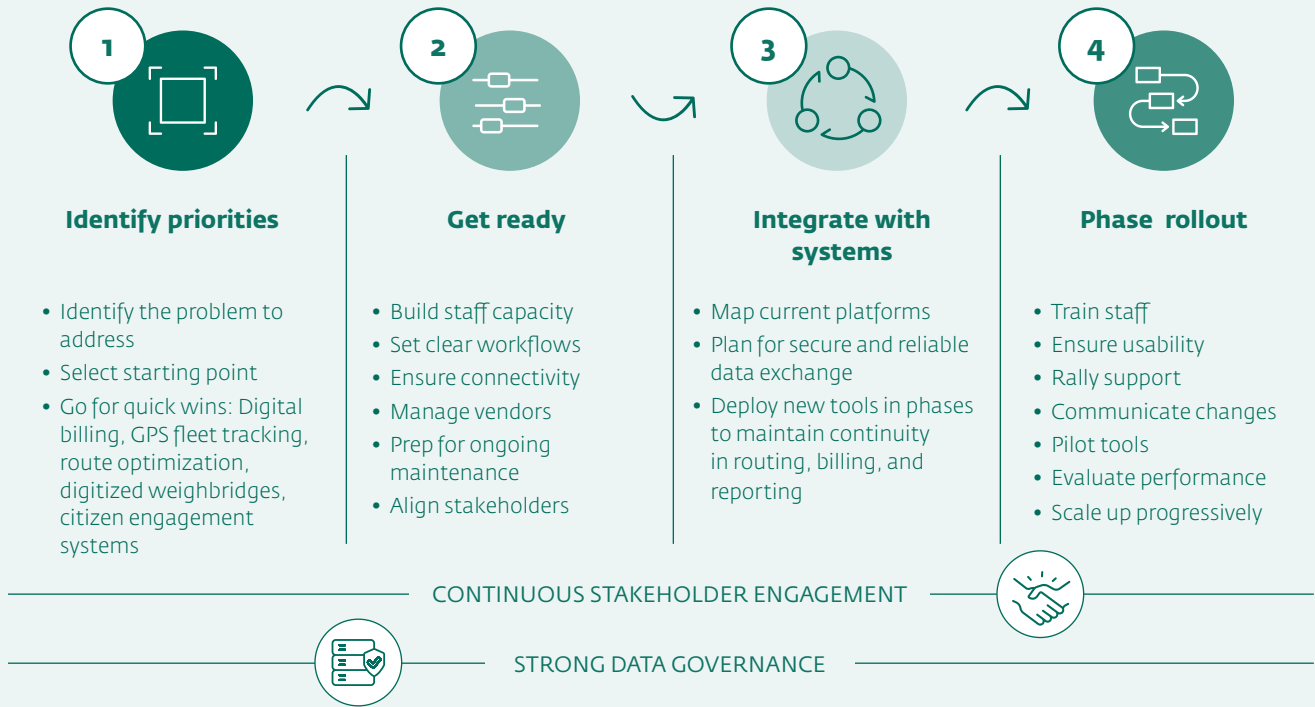
**Digitalization consistently offers low-cost, high-impact operational returns:** Compared with spending on physical infrastructure, digitalization represents a small share of cost while rapidly unlocking benefits in reduced fuel use, overtime, service failures, and overall cost.

# Report highlights

Deploying the right digital tools throughout the waste management lifecycle leads to positive outcomes.



**Implementation of the right digital tools is an ongoing process** that requires attention to strong data governance, prioritized needs, baseline and improvement monitoring, system and resource capabilities, and stakeholder engagement.



**Findings from case studies of cities around the world** quantify the value of digitalizing waste management systems.<sup>1</sup>

**Demonstration projects in Chengdu and Suzhou, China** showed how connected digital systems combining education, incentives, smart bins, and centralized sorting can improve sorting accuracy up to:

**98%**

**An initiative in Cité el Habib, Tunisia** showed that route analytics and telematics can reduce:

Collection time by up to: **57%** and fuel use by: **29-48%**

---

**A pilot in Seoul, Republic of Korea** showed that Internet of Things (IoT) smart bins can:

Reduce collection frequency by up to:	Help to lower costs by up to:
<b>66%</b>	<b>83%</b>

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**An initiative in Battambang, Cambodia** showed that integrated digital platforms combining Global Positioning System (GPS) tracking and digital billing can boost service coverage by:

**35-40%**

**Sorting facilities using optical sensors and artificial intelligence (AI) in Switzerland** helped achieve recovery rates of up to:

**95%**

for household plastics, in the context of supportive waste management policy.

# Solving Waste Problems with Digital Tools



## Operational Efficiency & Cost Reduction



Up to **57%**  
reduction in collection time.



**29-48%**  
reduction in fuel consumption.



## Improved Recovery & Material Purity



**>90%**  
material purity achieved.



## Enhanced Compliance & Revenue



**Automated data capture:**  
Streamlines regulatory adherence.



**Revenue protection:**  
Digitized billing reduces financial leakage.



## Citizen Engagement & Service Quality



**Service reliability:**  
Boosts participation, trust and responsiveness.



**Mobile apps:**  
Drastically reduce response times.

## Barcelona, Spain

- Complex waste collection system, overflowing street bins, collection challenges in dense urban districts.
- Integrated platforms for contract and quality management, RFID-enabled smart bins, underground pneumatic waste collection.
- Greater compliance, real-time monitoring, dynamic routing, and predictive analytics improved efficiency and service quality, while self-compacting bins cut emptying costs by 8x.

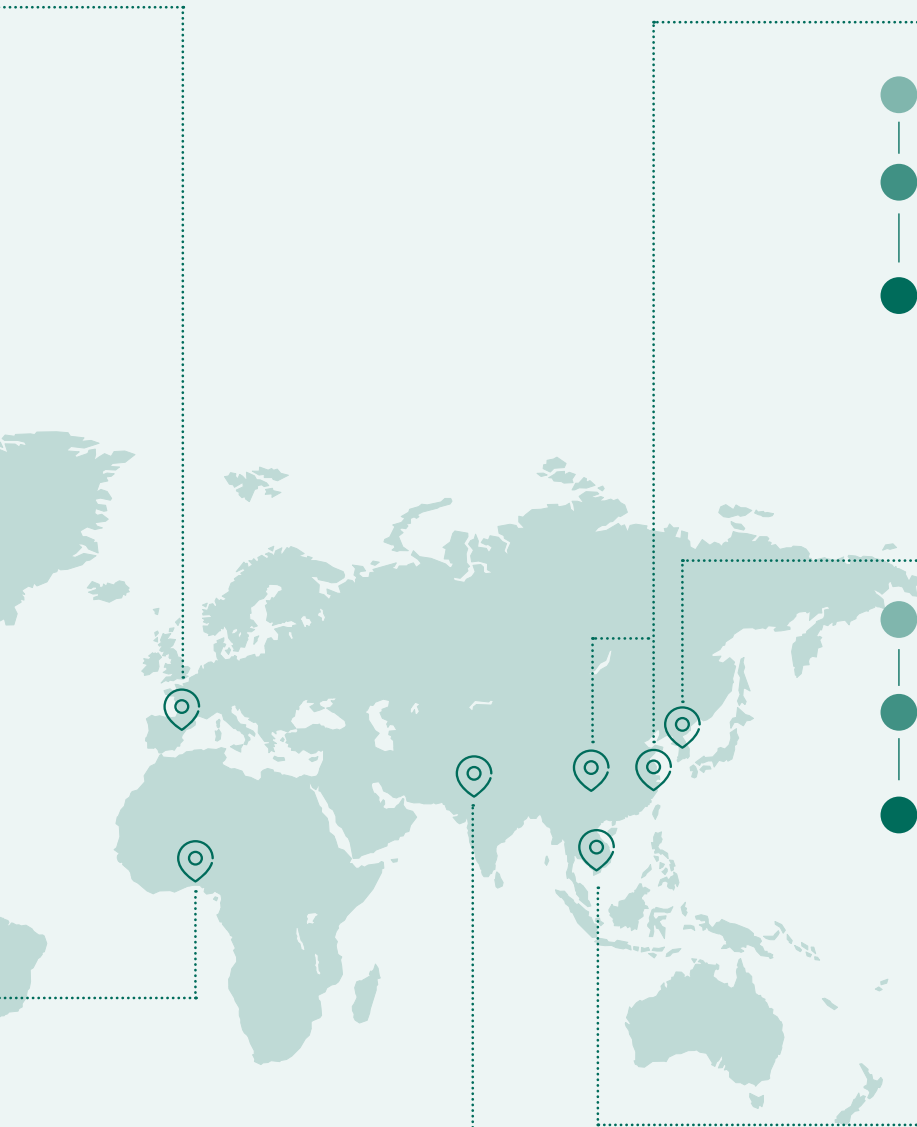
## San Francisco, USA

- Smart bins: 80% decrease in overflowing bins; 66% drop in street cleaning service requests.

## Cotonou, Benin

- Missed collections and limited visibility of fleet operations.
- GPS-enabled tracking of waste collection vehicles. (Costs: About \$465 to install per vehicle; \$23 month per unit.)
- Fewer missed pickups, improved route compliance, and fuel savings, alongside a ~9% increase in waste collection (430k t to 470k t) and ~500 fewer landfill trips, while real-time monitoring reduced fuel theft and extra payment demands.

● Problem   ● Solution   ● Outcome



**Lahore, Pakistan**

IoT sensors and fleet analytics: Fleet management and optimization reduced fuel use by 29%, lowered maintenance costs by 18%, and improved route efficiency by 32%.

**Chengdu & Suzhou, China**

- Irregular, low-volume, poor quality household recycling.
- QR-tracked AI recycling machines with digital marketplaces, IoT logistics.
- Higher household participation and recycler supply, achieving 98% sorting accuracy with 5,778 t of plastics diverted, while food waste separation rose from 5% to 40%.

**Seoul, Republic of Korea**

- Overflowing bins, inefficient fixed routes, low food recycling.
- RFID food-waste charging/ Pay-As-You-Throw (PAYT).
- Cleaner streets and more reliable collections, with food-waste recycling rising from ~2% to ~98%, alongside smart bins reducing collection costs by 83% and frequency by 66%, while total food waste fell by 10% as residents responded to weight-based digital fees.

**Battambang, Cambodia**

- Low payment compliance, limited waste service coverage.
- Digital billing with mobile payments for households, GPS tracking of collection vehicles.
- Higher fee collection through digital billing and expanded service coverage, increasing from approximately 40% to 75–80%.

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# Section 1

## Introduction

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**Municipalities and waste management companies are under constant pressure to find efficiencies and improve the management of waste under their jurisdiction. With global material consumption set to nearly double from 2017 levels by 2060, transitioning from a linear to a circular economy is increasingly urgent.<sup>2</sup> Circularity reduces waste and greenhouse gas emissions, while strengthening the economy and supply chains through material security, resource efficiency, cost savings and job creation.<sup>3</sup>**

Digitalization is a strategic asset for waste management, and critical to accelerating the transformation to a circular economy.

It offers practical solutions to longstanding waste management challenges such as poor data, disengaged citizens and businesses, inefficient use of waste infrastructure, and weak links across the waste value chain. If harnessed effectively, digitalization can help municipalities address these problems. It can also help waste management companies remain competitive, improve their financial resilience, and comply with stricter regulatory and climate requirements.

By enhancing data collection and management, such as through the use of internet-connected sensors, digitalization improves visibility, traceability, and accountability across the waste value chain. This translates into stronger stakeholder trust, more efficient operations, improved access to finance, and a more credible path toward meeting regulatory and climate commitments. These improved data flows also create a real-time feedback loop between operations and policy, allowing municipalities to assess performance, understand behavioral responses, and adapt strategies accordingly.

### Box 1.1

#### Experience from Zagreb Holding

The need for practical, action-oriented knowledge on digital solutions for waste management was identified as a result of IFC's collaboration with Zagreb Holding, a company fully owned by City of Zagreb in Croatia. IFC has provided Zagreb Holding with access to commercial finance, along with technical assistance on:



Digitalization strategy



Implementation planning for advanced digital solutions for waste management and circular economy.

This work highlighted the gaps in readily available knowledge for cities around the world. They need this knowledge to select the right digital solutions for their context and challenges and to successfully roll them out.

Zagreb has already implemented digital tools such as telematics on waste collection trucks and a mobile app for two-way communication with citizens. The implementation of these tools has resulted in:

- Improved operational visibility
- Better monitoring of waste collection activities
- Strengthened communication and transparency between the service provider and citizens

Next the city is planning to introduce smart bins equipped with RFID chips and barcode labels on containers for all recyclable waste fractions (paper and cardboard, plastic, and bio-waste), along with an integrated data analytics system. The insights generated will help optimize collection routes, improve operational efficiency, and support evidence-based waste management in line with circular economy principles.

These data-driven capabilities allow service approaches to be redesigned for greater efficiency, support more transparent KPI setting and tracking, and increase accountability. They also support auditable reporting to regulators and funders and demonstrate environmental benefits like emissions reductions and improved material recovery.

Digital tools such as smart bins, route optimization software, and blockchain-based traceability platforms are already improving waste systems worldwide. However, many municipalities and waste management companies need structured strategies and actionable insights to support informed decision-making, and effective implementation.

A common misconception is that digitalization requires substantial upfront investment. In reality, many digital solutions generate quick returns. Compared with traditional infrastructure costs, digitalization represents a relatively small investment that can mitigate rapid

waste growth and keep pace with urbanization, tightening climate commitments, and shrinking budgets, when such investments are tailored to local needs and service conditions.

### Technical notes

**Satellite positioning:** This report uses GPS as a recognized shorthand for satellite positioning. However, GPS is but one constellation within the Global Navigation Satellite System (GNSS) family. In practice, most modern receivers are multi-GNSS and track several constellations at once.

**Units of measurement:** This report uses tonnes (metric tonnes) or tons (US short tons) exactly as the measurement appears in the original data sources. To maintain accuracy, figures have not been converted unless explicitly stated.

## This report demonstrates how digital tools can help operators and municipalities reap the benefits of digitalization by:



Increasing separation at source, boosting participation among waste service users, and reducing contamination with simple engagement tools such as SMS/app/Radio-Frequency Identification (RFID).



Reducing operational impacts and preventing inefficiencies through optimizing routes and changing driver behavior to lower kilometers traveled, fuel use, and overtime.



Increasing resource recovery through improved visibility of materials and AI-enabled sorting at facilities.



Enhancing accountability and revenue generation by improving access to feedstock and enabling the sale of processed materials through digital trading platforms and marketplaces.

Such benefits accelerate circularity, improve material tracking, heighten transparency, and strengthen system resilience, while supporting policy targets. Through improved data collection and visibility, digitalization also plays a critical role in system-level planning and governance.<sup>4</sup>

## This report includes:



**Sector overview:** Providing context on challenges facing the waste management sector and the value in addressing the challenges through digital solutions.



**A guide to digital tools as the waste system evolves:** Grouped based on operational value created.



**City case studies:** To highlight quantifiable benefits of digitalization.



**Recommendations:** Important takeaways for cities and waste management companies that want to enhance their operations, improve efficiency, and increase citizen satisfaction.

Figure 1.1

## Research methodology



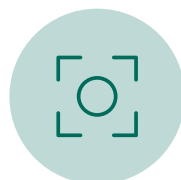
### Primary research

- 7 interviews
- Program officers, consultants, waste management experts, technology and digital tool suppliers
- Representatives from Benin, Cambodia, China, Republic of Korea, and Spain
- Focus on service challenges, procurement constraints and enabling conditions



### Secondary research

- Literature review
- Municipal reports
- Independently verifiable case documentation
- Vendor materials as corroborated by public sources



### Research standards and limitations

- Findings, such as fuel savings, overflow reduction, drawn from city/operator-reported results where available, otherwise, a range is provided
- Results achievement dependent on: governance, data quality, route design, citizen behavior, infrastructure, and vendor capability
- Results influenced by other factors in addition to digitalization; difficult to disaggregate and quantify direct impacts from digitalization



### Global waste management knowledge base

- World Bank Group flagship study: "Waste Management in the Middle East and North Africa"
- United Nations Environmental Program: "Global Waste Management Outlook 2024"

## Section 2

# The case for digitalizing the waste sector

**This chapter presents the challenges facing the waste sector as it transitions to full circularity and identifies ways that digitalization can help to address the challenges.**

1. Basic service access
2. Operational efficiency
3. Stronger system performance
4. Fully circular systems

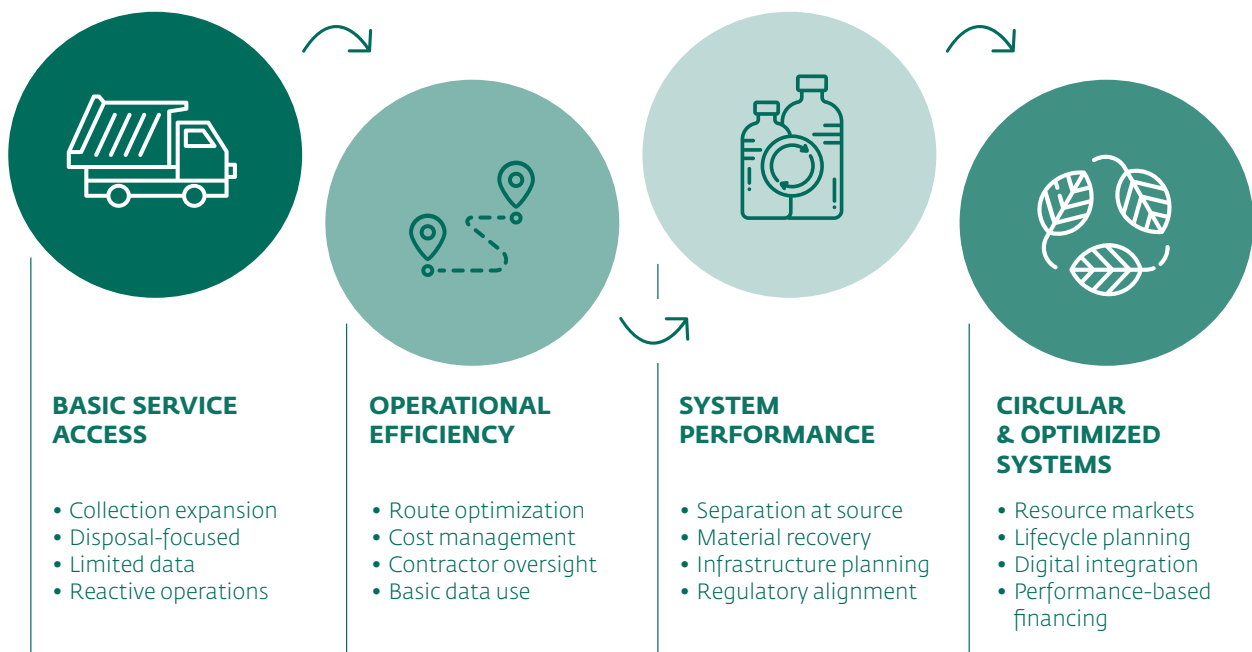
## The waste system circularity evolution

Waste systems typically evolve and transition to full circularity through four broad stages, through four broad stages:

Digital tools can support progress at each stage, from basic visibility and control to more advanced planning, compliance, and performance. For municipalities and operators, understanding the current stage of your system, as well as future circularity goals, enables identification of immediate, mid-term, and long-term priorities and the selection of appropriate tools.

Figure 2.1

## The evolution of waste systems from basic service provision to full circularity



## Challenges facing the waste sector

Waste volumes are increasing dramatically. These volume increases pose a significant challenge for the entire waste sector.

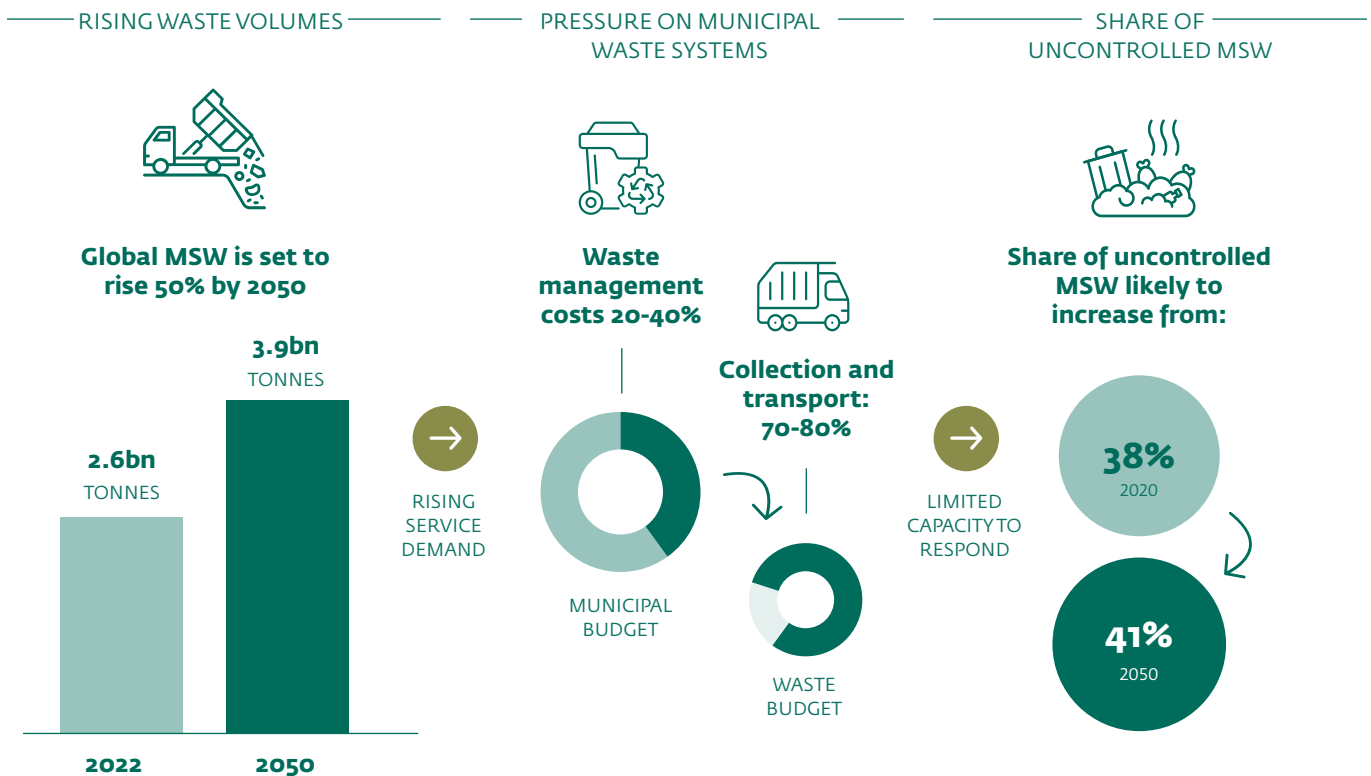
Global municipal solid waste (MSW) generation is set to rise by 50 percent by 2050 (from 2.6 billion tonnes in 2022 to 3.9 billion tonnes), with waste volumes in lower-income countries expected to more than double—and in some regions triple—by 2050, putting profound pressure on waste systems.<sup>5</sup> Despite limited resources, municipalities and waste management companies are under pressure to manage these increasing waste volumes.

The costs of inaction are significant: \$361 billion annually in global health and environmental impacts from uncollected waste and disposal through open dumping and burning, according to 2020 estimates.<sup>6</sup> Also of concern: the share of uncontrolled MSW is likely to increase from 38 percent in 2020 to 41 percent by 2050. Rising waste volumes, pressure on municipal budgets, and the growing social and environmental costs are driving the need for more efficient, data-driven waste systems (figure 2.2).

In many low- and middle-income countries, waste management accounts for a high proportion of municipal budgets, with collection and transport making up most of these costs. This represents an opportunity for municipalities in these countries: deploying the appropriate digital tools can drive significant efficiency gains.

Figure 2.2

### Rising waste volumes and the increasing cost of inaction



Sources: Cook, Ed et al. (2026) — global; UN-Habitat (2010) — developing countries; UNEP/ISWA (2024) — global.

The sector faces other challenges as well, including:

**Tightening regulatory and compliance requirements:**

Governments are imposing increasingly stringent regulations, climate targets, and compliance requirements, necessitating accurate reporting and traceability. For example, the EU's Packaging and Packaging Waste Regulation 2025/40 sets challenging recycling targets for specific material fractions. This represents a call to action for those investing in and operating waste management systems. Compliance without robust systems is resource-intensive and prone to errors, exposing operators to penalties and reputational risks.<sup>7</sup>

**Fragmented value chains:** Waste systems involve multiple actors, including municipalities, waste management companies, recyclers, and regulators, often operating in silos. This results in poor coordination, duplicated efforts, and gaps in accountability.

**Unauthorized disposal:** Unauthorized disposal remains a persistent issue, driven by cost avoidance and lack of enforcement. Detecting and preventing such activities is challenging without systematic oversight, adding strain to waste management companies.

**Inefficient systems and manual processes:** Many waste management companies continue to rely on paper-based workflows and manual data entry, which are time-consuming, error-prone, and lack real-time visibility. Inefficiencies in route planning, scheduling, customer billing, and plant operations increase costs and impact on revenues.

**Poor quality data and lack of transparency:** Incomplete or inaccurate data makes it difficult to establish baselines, forecast trends, assess future infrastructure needs, and demonstrate compliance. This situation often leaves municipalities with limited visibility into service delivery, reducing their ability to effectively govern and steer essential urban services. Lack of auditable data undermines trust among regulators and stakeholders.

**Weak citizen / customer engagement and service:**

Low awareness and poor disposal practices by households or businesses lead to contamination and underuse of services. Inconsistent service provision further reduces customer satisfaction and limits the revenue that can be collected through user fees. Together, these factors weaken financial sustainability, reduce material recovery, and make it harder for municipalities and waste management companies to plan, optimize services, and invest in system improvements.

## Implications for municipalities

Municipalities face the dual challenge of rising waste volumes and constrained budgets. In many developing countries, waste management already consumes 20–40 percent of municipal budgets, with 70–80 percent directed toward collection and transport.<sup>8</sup> Despite these high costs, service levels often remain inadequate, and more than half of urban waste may go uncollected. Municipalities are also under increasing regulatory pressure to improve environmental performance, expand service coverage, and enhance transparency and accountability to citizens. Fragmented systems, limited data, and low citizen engagement further complicate planning, investment prioritization, and service operations. Without reliable data on waste generation, service performance, and material flows, municipalities struggle to target investments effectively, sequence infrastructure development, and allocate resources where they deliver the greatest impact. Strengthening the use of digital data is critical not only for operational improvement but also for informing capital planning and financing decisions. As waste volumes grow, municipalities will need to deliver better services and prioritize investments without proportionally increasing expenditures or raising user fees.

## Implications for waste companies

Waste companies are similarly affected by rising waste volumes. However, the pressures they face are typically more commercial than fiscal. Companies must meet stricter

regulatory requirements, deliver higher quality service, and remain competitive in bidding for municipal contracts and commercial clients. Inefficient operations, whether due to outdated routing, poor asset utilization, or limited data visibility, directly affect profitability and competitiveness. As municipalities increasingly prioritize performance-based contracting and transparency, waste companies that can demonstrate efficiency, reliability, and data-driven service delivery will gain a clear competitive advantage.

## How digitalization helps

Digitalization uses both hardware and software technologies to improve existing data collection and management, processes, workflows, and services. This digital transition drives development, generating growth, creating jobs, and improving waste management. Digital technologies:



**Boost efficiency** as services become cheaper, quicker, or more convenient.



**Promote innovation**, slashing costs of transactions.



**Increase inclusion** by providing access to services that were previously out of reach.<sup>9</sup>



**Link operational signals** to workflows and decisions.

Digital technologies use modern electronic computer systems to accurately convert information about the real world into digital signals that can be processed, stored, and transmitted at high speed, enabling the efficient processing and use of information. Digital waste management tools provide a practical and scalable pathway for municipalities and waste companies to address the challenges they face.

These tools can:

- 1 Strengthen data quality, enabling better planning, forecasting, and decision making.
- 2 Increase citizen and business engagement through digital service interfaces and feedback channels.
- 3 Improve operational efficiency through optimized routing, automated workflows, and real-time monitoring.
- 4 Enhance transparency and compliance, supporting reporting requirements and performance-based contracting.
- 5 Maximize existing assets, reducing the need for costly infrastructure expansion.



**Digitalization costs** are a small fraction of the infrastructure and operational budgets they can benefit.

A common misconception is that digitalization requires substantial upfront investment. In practice, although costs vary widely, many digital solutions deliver rapid returns by improving the efficiency of existing fleets, staff, and infrastructure.

Digitalization costs are a small fraction of the infrastructure and operational budgets they can benefit. (See Appendix for an example of how routing optimization software can significantly reduce fuel use and fleet wear, often at a fraction of the cost of purchasing additional vehicles to compensate for inefficient operations.)

While digital adoption is accelerating in many developed countries, uptake in developing countries remains limited. This creates significant opportunities for leapfrogging traditional infrastructure constraints and building more resilient, efficient, and transparent waste systems.



**For municipalities,** digitalization offers a way to stretch limited budgets while improving service quality.



**For waste management companies,** it provides a competitive edge in an increasingly performance driven market.



**For both,** it represents a critical enabler of long-term sustainability and system modernization.

Often seen as an operational efficiency measure, digitalization in waste management also plays a critical role in system-level planning and governance. Municipalities need reliable information to plan, regulate, and finance waste services effectively. Digital tools provide the data foundation needed for adaptive waste management strategies. By integrating operational data into planning

and decision-making, municipalities can continuously evaluate service performance and system outcomes, updating waste management plans and refining standards. Digital platforms also enable transparent management of performance-based contracts and strengthen compliance monitoring and reporting to regulators, enhancing the ability to demonstrate environmental benefits.

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## Section 3

# A guide to digital waste solutions

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**The guidance in this chapter helps municipalities and waste management companies identify the specific digital tools they can use to fix common service problems.**

Figure 3.1 shows the various types of tools, grouped according to the value they add in addressing four main operational challenges:



After reviewing the tools, use the checklist in table 3.1 to identify the specific operational challenges you face and the digital tools that can help address them. (For more detail on

the tools, the challenges they address, and their costs and benefits, please see the Appendix.)

Figure 3.1

## Digital waste solutions to address four operational challenges

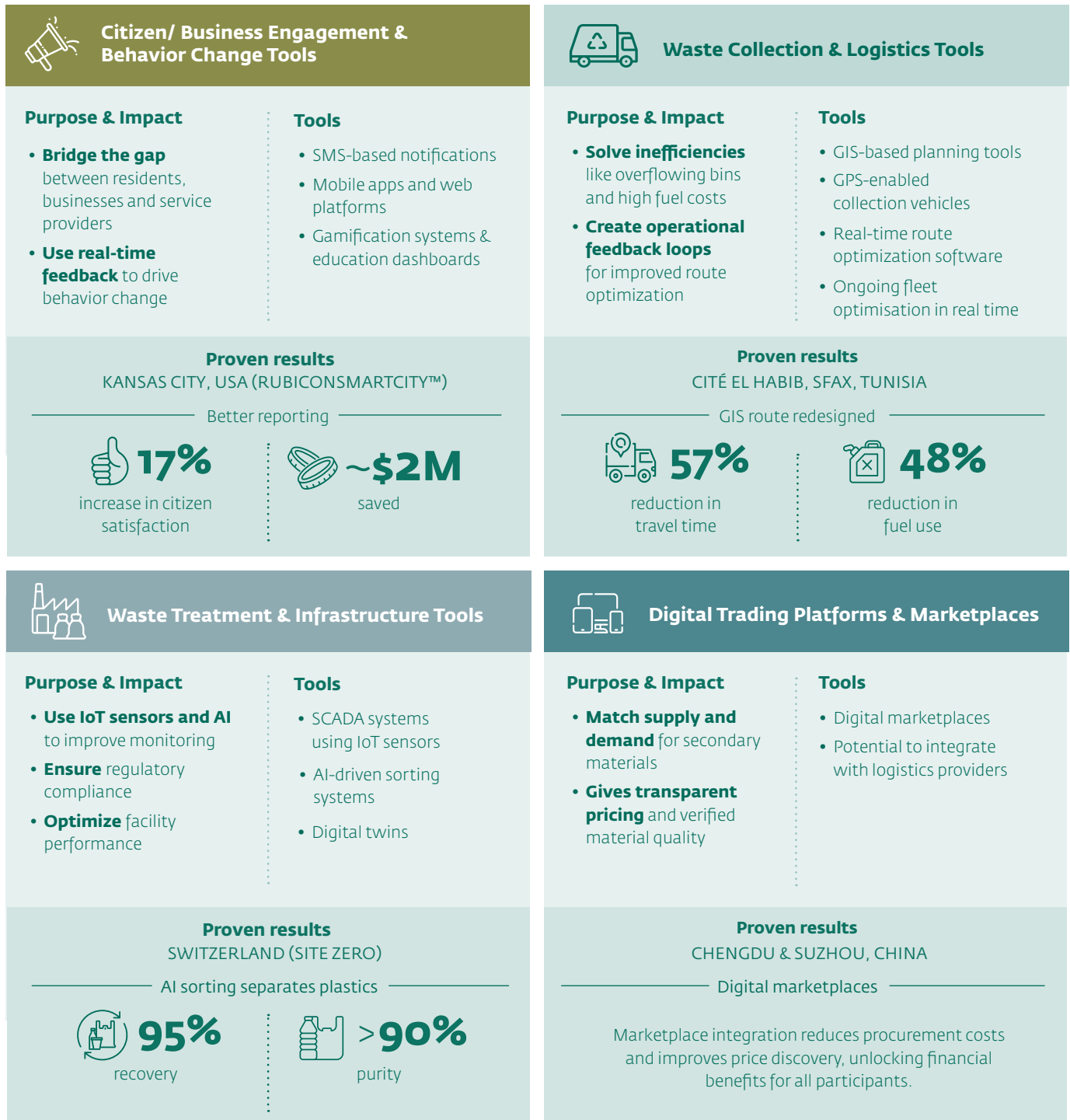




Table 3.1

## Digital tools checklist

Category	Operational Challenge	Digital Waste Solutions
 <p>Applies across all categories</p>	<p><b>Limited data for planning, reporting, or oversight</b></p> <p><b>Problem:</b> Municipalities and waste management companies cannot access reliable, consistent, or timely data.</p>	<ul style="list-style-type: none"> <li>• Digital reporting tools</li> <li>• Traceability tools (QR / RFID)</li> <li>• IoT sensors</li> </ul>
 <p>Citizen/business engagement and behavior change tools</p>	<p><b>Low participation or high contamination</b></p> <p><b>Problem:</b> Households and businesses lack clear guidance, incentives, and transparent feedback.</p>	<ul style="list-style-type: none"> <li>• SMS based notifications</li> <li>• WhatsApp or basic messaging-app broadcasts</li> <li>• Bulk email alerts</li> <li>• Mobile apps and web platforms</li> <li>• Education dashboards</li> <li>• Gamification and incentive systems</li> <li>• RFID access controlled containers</li> <li>• Sensors &amp; AI applied at bin pick-ups</li> </ul>
	<p><b>Weak cost recovery or payment compliance</b></p> <p><b>Problem:</b> Paper-based billing and manual fee collection hinder revenue performance.</p>	<ul style="list-style-type: none"> <li>• Digital billing systems</li> <li>• Mobile payment platforms</li> <li>• Customer billing and service portals</li> </ul>
 <p>Waste collection and logistics tools</p>	<p><b>Low visibility over daily operations</b></p> <p><b>Problem:</b> Teams lack real-time oversight of collections, fleet status, and service completion.</p>	<ul style="list-style-type: none"> <li>• GPS enabled collection vehicles</li> <li>• Vehicle telematics and diagnostics</li> <li>• Digital weighbridges</li> <li>• Digital reporting tools</li> <li>• Real-time dashboards / service verification systems</li> </ul>
	<p><b>Missed, late, or irregular collections</b></p> <p><b>Problem:</b> Inconsistent service delivery results in complaints and lower trust.</p>	<ul style="list-style-type: none"> <li>• GPS enabled collection vehicles</li> <li>• IoT enabled smart bins (e.g., with fill-level sensors)</li> <li>• Real-time route optimization</li> <li>• Mobile apps for reporting missed bins</li> </ul>
	<p><b>Inefficient routes and high fuel use</b></p> <p><b>Problem:</b> Routes are static and don't reflect actual conditions or fill levels.</p>	<ul style="list-style-type: none"> <li>• GIS based route planning</li> <li>• Vehicle telematics (fuel + driver behavior)</li> <li>• IoT enabled smart bins to reduce unnecessary trips</li> <li>• Real-time route optimization</li> </ul>
	<p><b>Implement specialized collection systems</b></p> <p><b>Problem:</b> Dense population areas/new-build communities or specialized systems require specialized solutions.</p>	<ul style="list-style-type: none"> <li>• Pneumatic waste collection systems</li> <li>• Digitalized DRS infrastructure (RVMS)</li> <li>• RFID tags for implementing PAYT systems</li> </ul>

Category	Operational Challenge	Digital Waste Solutions
 <p>Waste treatment &amp; infrastructure tools</p>	<p><b>Manual or error prone processes at treatment facilities</b></p> <p><b>Problem:</b> Manual processes at waste treatment facilities cause slow processing, high error rates, and inconsistent operation and output quality. Without intelligent control systems, these facilities suffer from inefficiency and heightened risk of non-compliance.</p>	<ul style="list-style-type: none"> <li>• Digital weighbridges</li> <li>• Digital reporting tools</li> <li>• Intelligent control systems</li> <li>• SCADA + IoT monitoring</li> <li>• Sensor-based digital sorting</li> <li>• Camera &amp; AI-enabled sorting systems</li> <li>• Digital twins for planning and optimization</li> </ul>
 <p>Digital trading platforms and marketplaces</p>	<p><b>Difficulty finding buyers or accessing feedstock</b></p> <p><b>Problem:</b> Recycling markets lack transparency, quality assurance, and connections.</p>	<ul style="list-style-type: none"> <li>• Digital trading platforms / marketplaces</li> <li>• Material traceability tools (QR / RFID)</li> <li>• Online quality verification systems</li> </ul>

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## Section 4

# Taking action: *Implementing digital solutions*

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**Now that you have identified the tools that can address the specific challenges facing your system, the question becomes how to implement them. This chapter lays out the practical conditions for successful deployment.**

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**Strong data governance must underpin all digital initiatives.**

Digital waste systems generate operational data on service delivery, infrastructure performance, household or business customer participation, and material flows, such as from routing, billing, PAYT schemes, and facility monitoring. The data supports planning, contract oversight, performance management, and regulatory reporting. A lack of clear governance and control can put this information at risk and could limit its long-term value.

As systems become more connected, governance increasingly must include privacy safeguards and cyber-resilience to protect service continuity and public trust. See box 4.1 for a checklist on what's needed for strong data governance.

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**Successful implementation requires alignment across policy, funding, service delivery, and operational teams from the outset.**

It is important to note here that digital tools improve waste systems only when the right operational, institutional, and commercial conditions are in place. Municipalities and waste companies often focus on selecting technology, but implementation success depends equally on data

### Box 4.1

#### Data governance checklist

- ✓ **Define ownership of data** generated through routing, billing, facility monitoring, and engagement tools.
- ✓ **Define the system of record for each dataset**, and assign data-quality responsibilities, including validation, correction, and periodic audit to specific teams, such as operations, IT, facility managers, or contractors.
- ✓ **Establish cybersecurity protections:**
  - Anonymize data collection.
  - Set controls: encryption, multi-factor authentication, testing, incident response.
  - Manage vendor risks via audits and contractual obligations.
  - Validate controls through audits and testing.
- ✓ **Ensure traceable data use and change history:** Secure full access and audit rights to both raw operational data and processed analytics outputs for oversight and performance management.
- ✓ **Enable portability between systems** to support future procurement and integration.
- ✓ **Set responsibilities** for storage, security, and lifecycle management.
- ✓ **Incorporate data governance requirements** into procurement and vendor agreements, including interoperability requirements to reduce risk of vendor lock-in.
- ✓ **Use data effectively to support strategic objectives** by setting practical KPIs that can be tracked using the available data.
- ✓ **Build internal, vendor, and end user capacity** through outreach and training.
- ✓ **Ensure compliance** with national data protection and cybersecurity requirements.

governance, staff adoption, integration with existing systems, and clear operational priorities—as well as on

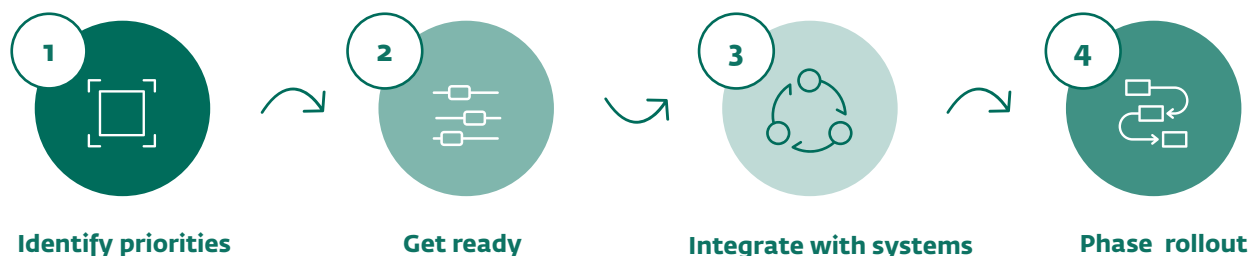
regulatory expectations, financing requirements, and service reform objectives (table 4.1).

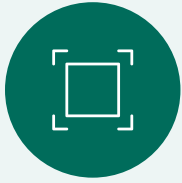
Table 4.1

### Key factors and actions for successful deployment of digital solutions

Enabling factor	Why it matters in waste operations	Typical actions
Define the operational problem	Tools work best when solving specific issues, such as missed collections, weak billing, low recycling participation.	Identify priority service challenges before selecting tools.
Starting point selection	Foundational tools deliver early gains and reduce risk.	Begin with billing, GPS, routing, or facility monitoring before introducing advanced systems.
Data governance	Operational data supports routing, billing, infrastructure planning, and compliance.	Retain ownership of data, ensure access and portability, avoid vendor lock-in.
Operational readiness	Tools fail if staff, workflows, and infrastructure cannot support them.	Assess capacity, skills, connectivity, and processes before deployment.
Integration with legacy systems	Existing billing, fleet, and facility systems must continue to function.	Conduct technical assessment and phased integration.
Lifecycle economics evaluation	Total cost of ownership (TCO) planning prevents budget shocks and helps maximize long-term value from digital investments.	Map all lifecycle costs, including installation, maintenance, upgrades, and end-of-life.
People and adoption	Staff and citizens determine whether tools are actually used.	Provide training, communication, and support.
Phased rollout	Large deployments increase risk and cost.	Pilot first, evaluate, then scale.

What follows is a step-by-step process for implementing digital solutions.





## Step 1 *Identify priorities*

To ensure that digitalization is effective, it is important to define your operational priorities clearly, because simply selecting a technology will not guarantee results. By identifying the specific service challenges that you aim to resolve, you will be more likely to select tools that deliver measurable improvements.

By starting with specific service challenges, such as missed collections, weak billing, rising fuel costs, or poor recycling participation, you are more likely to select tools that deliver measurable improvements.

### Select the starting points

Typical digital tool starting points include:

**Digitizing billing and payment systems** to improve cost recovery and transparency.

**Introducing GPS fleet tracking** to strengthen oversight of collection rounds.

**Deploying route planning tools** to reduce travel time, fuel use, and missed collections.

**Digitizing weighbridges and facility reporting** to improve data accuracy and compliance.

**Building management capacity** to oversee implementation and vendor performance.

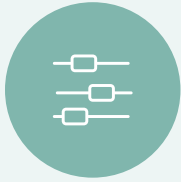
**Aligning digital tools** with existing service models, contracts, and regulatory requirements.

**Planning for ongoing operational needs** such as maintenance, support, and updates.

**Strengthening customer and citizen engagement tools** to improve participation.

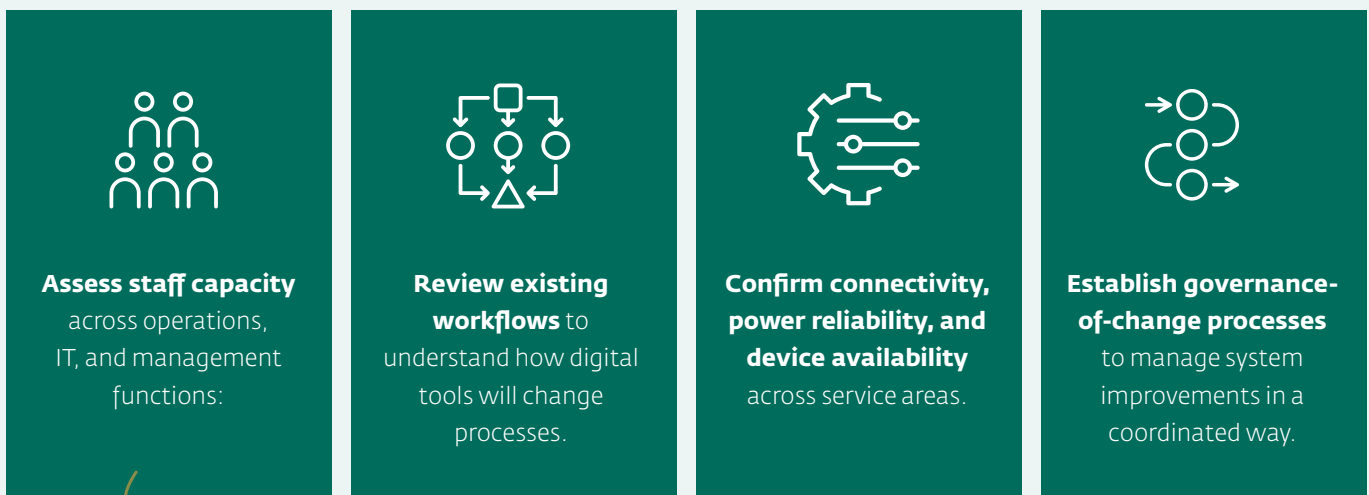
**Ensuring compliance** with national data protection and cybersecurity requirements, particularly where systems capture billing, geolocation, or customer engagement data.

More advanced tools, such as real-time optimization, AI-enabled sorting, or digital marketplaces, are most effective once these operational foundations and reliable data systems are in place.



## Step 2 *Get ready for rollout*

Technology delivers value only when organizations are prepared to use and sustain it in daily operations. Among the actions needed to prepare for digital tool adoption:



If you have limited technical capacity, starting with simpler tools requiring little integration could prove more practical. Those with stronger digital capabilities could opt for more advanced, complex systems.

Note that successful digitalization depends on engagement beyond operational teams. Municipal leadership, policy advisors, regulators, financiers, service providers, and communities all influence implementation pathways, funding decisions, and adoption.

Early alignment and effective change governance help ensure that digital investments support regulatory priorities and reporting obligations, financing and procurement decisions, service delivery models and contractual arrangements, and public acceptance and participation.

To strengthen alignment and reduce implementation risk, consider making use of stakeholder mapping and structured engagement through workshops, procurement dialogue, and pilot collaboration.



### Step 3

## *Integrate tools with existing systems*



**Your systems may rely on legacy billing, fleet, and facility systems that must continue functioning as digital tools are introduced.** Successful digital deployment will depend on early system mapping, procurement that considers integration requirements, and phased implementation that maintains continuity of routing, billing, and reporting while preserving historical data.



**Integration planning should involve coordination** between municipalities, waste companies, technology vendors, and financing partners to ensure continuity of service and alignment with contractual and regulatory requirements.



**Integration can also increase exposure to operational disruptions** if systems are not securely connected. To reduce these risks, the planning process should also cover installing access controls, cybersecurity measures, and continuity arrangements to protect service delivery.



### Step 4

## *Phase rollout*

A phased approach reduces risk and allows you to refine tools before full deployment. Consider using pilots to test tools in specific routes, service areas, or facilities before wider rollout. Doing so helps identify integration requirements, training needs, and operational impacts under real service conditions, while also establishing the foundations for continuous improvement even beyond full implementation. Note that high-quality measurement is critical during the pilot phase, to assess viability and scale-up potential.

If the pilot produces a positive business case, with operational benefits demonstrated and organizational readiness improved, then scale up can follow. A phased implementation can proceed service area by service area, aligned with contractual and regulatory frameworks.

Useful phasing measures include:

**Piloting** in selected routes, facilities, or districts.

**Monitoring** pilot performance and assessing pilot cost-benefits.

**Testing** integration with existing operational and data systems.

**Refining** workflows, training, and operational processes.

**Engaging** users and stakeholders during early deployment.

**Evaluating** operational performance and user feedback.

**Adjusting** workflows, training, and configuration.

**Scaling** gradually across service areas.

**Monitoring** system-level performance indicators and financial outcomes before, during, and after expansion.

Phased deployment allows you to build confidence, demonstrate early results, and embed the principle of continuous improvement, enabling digital tools to deliver best value over time. (See box 4.2 for a tool adoption checklist.)

Box 4.2

**Tool adoption checklist**

Uptake and adoption improve when users can see that digital tools make their daily tasks easier, safer, or more reliable.



Provide practical training for staff, including collection crews, drivers, facility staff, and supervisors.



Offer ongoing support and refresher training.



Ensure tools align with real operational workflows rather than adding parallel processes.



Engage citizens and businesses where participation affects service outcomes.



Communicate clearly how tools will improve service delivery and operational performance.



Address concerns from staff and informal actors early to reduce resistance.



Design systems that are simple to use in field conditions.

## Lifecycle planning for digital solutions

When planning a digitalization initiative, several considerations should underpin the process. We have already noted the critical nature of strong data governance. In aiming for optimal outcomes and demonstrable returns, other factors also play a role.

### Budgeting: Account for total cost of ownership

Digitalized systems carry a lifecycle cost profile that can differ from traditional waste solutions. Software-based tools often distribute costs over time, enabling you to avoid large upfront capital spending while benefiting from continuous performance improvements, assisted by updates and feature enhancements. Hardware such as sensors, IoT

devices, or telematics units may require periodic upgrade, repair or replacement. Setting a timetable for refresh cycles will ensure you retain efficient, capable, and secure technologies. See box 4.3 for issues to consider as you assess total cost of ownership.

Incorporating total cost of ownership (TCO) assessments into early planning helps account for future needs, ensuring that solutions provide high and sustained returns. In preparing a TCO assessment, consider all costs that accrue over the system's lifecycle, including:

- **Hardware-related expenditures:** Such as device installation, maintenance, and periodic upgrades or replacement.
- **Software and platform costs:** Licenses, subscriptions and cloud hosting.
- **Integration needs:** Data migration and interoperability with legacy systems.
- **Cybersecurity operations:** Such as security monitoring, patching, and incident response.
- **Connectivity costs:** For example, linking IoT devices and communication networks.
- **Operational elements:** Such as staff training, change-management support, and vendor oversight services.

#### Box 4.3

### Operational risks and considerations

When assessing total cost of ownership, it is important to account for a range of risks that could increase lifecycle costs if not planned for. Among them:



#### Urban risks

- Theft
- Vandalism
- Damage to smart bins and tracking equipment



#### Capacity risks

- Availability of skilled local resources for routine maintenance and repairs
- Reliance on external vendors for hardware servicing



#### Equipment risks

- Timing and cost of software updates
- Availability of and access to spare parts

### Change governance

Ongoing oversight of the digitalization process is also an important component of lifecycle planning. This will ensure that updates, upgrades, and system improvements are introduced in a coordinated way to maintain performance and avoid unexpected costs.

## End-of-life and contingency planning

Lifecycle planning also includes end-of-life considerations, such as responsible recycling, decommissioning, and transition to next-generation systems. In addition, factoring in contingency allowances can help address unforeseen failures, scaling needs, or earlier-than-expected technology obsolescence.

Maximizing the useful life of digital assets, ensuring repairability, and planning for responsible end-of-life recycling also contributes to circularity by reducing environmental impacts. In addition, doing so allows for improved economic efficiency over time.

## People: Managing adoption and changing behaviors

Digital tools deliver benefits only when they are used consistently by staff and service users. Uptake and adoption improve when users can see that digital tools make their daily tasks easier, safer, or more reliable.

Increasing the rate of adoption will depend on usability, training, and alignment with daily work. Box 4.2 features a checklist of steps to take in ensuring uptake of your digitalization initiatives.

## Red flags: Pitfalls and risks to watch for

Digital waste projects often struggle due to operational rather than technical issues. Recognizing risks early improves the likelihood of successful deployment.

## Common risks include:



Insufficient stakeholder alignment across municipal leadership, waste companies, and service partners.



Technology rollout before operational processes are ready, or prior to piloting.



Unclear data ownership and governance.



Insufficient staff training and support.



Tool selection based on features rather than operational fit.



Lack of long-term funding for maintenance and upgrades.



Lack of alignment between digital tools and regulatory or financing requirements.



Limited interoperability or data access due to vendor specifications.

Addressing these risks early strengthens outcomes and protects investment.



### The bottom line

Digital tools are most effective when implemented as part of operational improvement rather than as standalone technology projects. Keep in mind that clear starting points, strong data governance, staff adoption, and phased implementation are more important than tool sophistication.

## Section 5

# Global evidence of digitalization's value: *Case studies of 5 cities*

Cities are extremely diverse in nature—no two are the same. The waste issues they grapple with are equally diverse. This chapter presents case studies of five cities in differing economic circumstances, to demonstrate the range of positive impacts that digitalization initiatives can have:

- 📍 **Barcelona, Spain:** High-income
- 📍 **Battambang, Cambodia:** Lower-middle
- 📍 **Chengdu and Suzhou, China:** Upper-middle-income
- 📍 **Cotonou, Benin:** Lower-middle-income
- 📍 **Seoul, Republic of Korea:** High-income

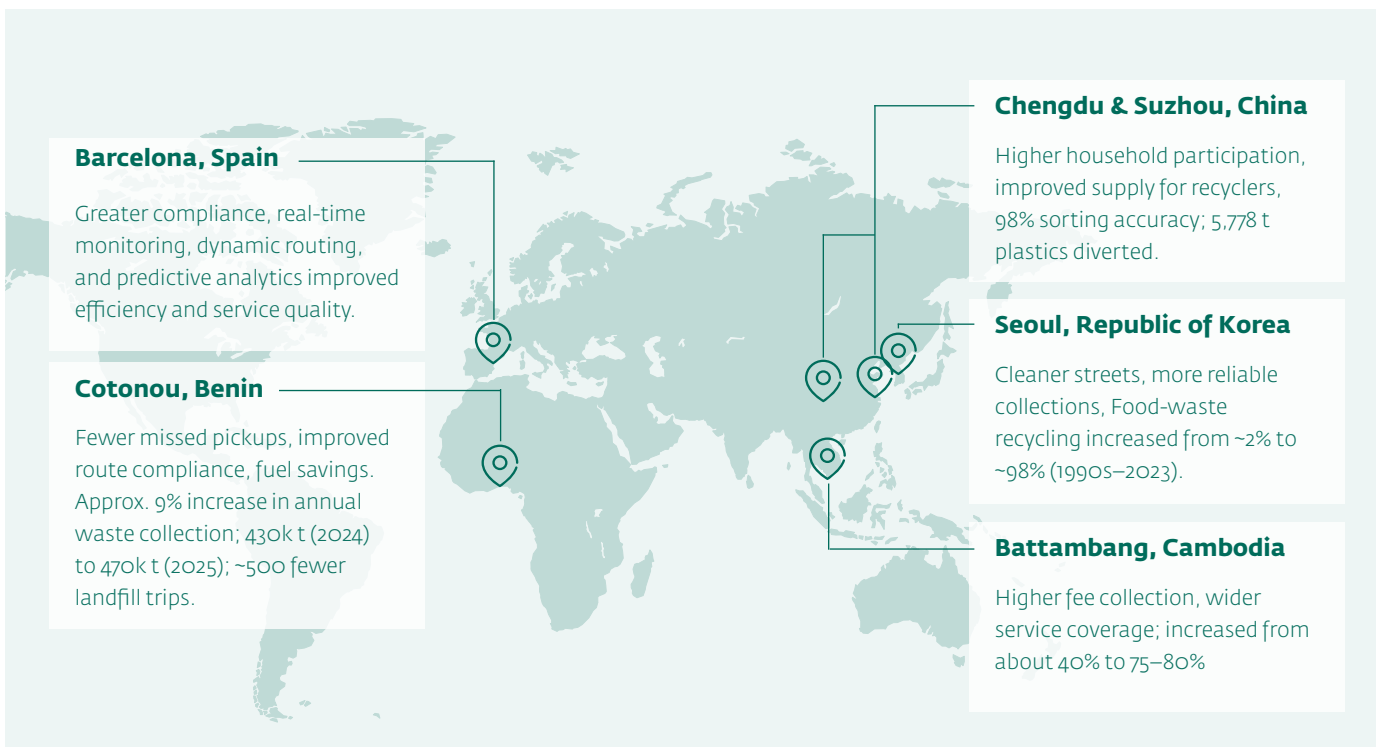
Box 5.1.

### World Bank country income classifications

**High-income country:** Economies with per capita gross national income (GNI) over \$13,935 and strong infrastructure, and well-suited for advanced digital systems.

**Upper-middle-income country:** Rapidly growing economies with GNI per capita between \$4,496 and \$13,935, expanding digital capacity but varying degrees of readiness.

**Lower-middle-income country:** Developing economies with GNI per capita of \$1,136 to \$4,495, where digital solutions often need phased investment or external support.



# Barcelona, Spain

## Modeling long-term commitment to digital modernization

### The waste challenge

- Drive for city clean up in run-up to hosting Olympics
- Complex and fragmented waste collection system
- Change in EU regulations to require more recycling, better data

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### The digital solutions

Decades-long commitment to digitalizing waste management systems

Underground pneumatic waste collection

Integrated platforms\*

RFID-enabled smart bins connected to municipal open-source IoT platform

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\*

- Sensor, GPS, RFID, and app data for real time operations
- Routing, QA, and contractor oversight:
  - App-based inspections
  - GPS-verified service completion
  - Data sharing

### Results

**8X**

Lower emptying costs through self-compacting bins

Strong governance, quality control, and robust data management

Global acknowledgment as a model for smart, clean cities

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Estimated 1–2% annual invoice adjustments through detecting missed or substandard services, via performance-linked pay and digital QA.

### Takeaways

- Digital tools** can work holistically to solve complex waste management challenges.
- Early investment in digital infrastructure** speeds adoption of new tech and supports circular goals.

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**Key requirements**  
for scalable digital systems

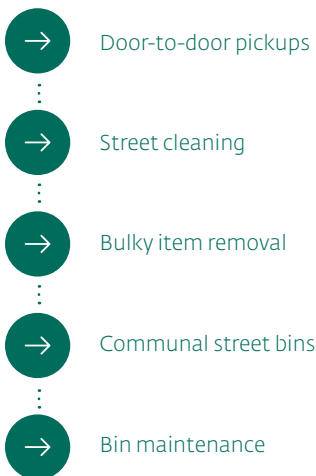
Strong data management	Interoperability
Performance-based contracts and robust QA processes	Citizen engagement to drive adoption and behavioral change

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**Barcelona's push for modernizing its waste management systems began with the 1992 Olympics, when the city faced overflowing waste containers, inefficient routes, and poor data management. Digitalization became essential to improve operations, track costs, and meet stricter EU recycling and waste separation regulations.**

Unlike cities with legacy systems, Barcelona's early investment in digital infrastructure now allows it to adopt new advanced models quickly. Today, its Zero Waste Plan and integrated digital platforms support circular economy goals.

Among the aspects of Barcelona's street cleaning and municipal waste collection systems:



The city stands out for its long-term planning, continuous upgrades, and wide range of interoperable solutions—making it one of the world's most advanced Smart City ecosystems and a valuable example of how digital tools can transform waste management over time.

Importantly, this transformation has been part of a wider cross-disciplinary roadmap, with waste serving as the leading demonstrator for digitalization. The changes have been incremental, with continuous upgrades and integration of advanced technologies over time.

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**The digital solution: Incremental approach; comprehensive strategy; transformative suite of digital tools**

Today, Barcelona has one of the most advanced and long-standing smart waste systems in the world. The city has deployed an extensive suite of digital tools to transform how it manages solid waste across the entire value chain. This digital ecosystem enables real-time monitoring, dynamic routing, asset management, quality control, performance-based contracting, and citizen engagement. Features include:

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Integrated platforms

.....  
GPS, weighbridges, telematics, billing systems, and citizen apps  
.....

Advanced tools:

- Pneumatic waste collection: Provides automated underground waste removal for approximately 200,000 residents and businesses, reducing traffic and noise from traditional refuse vehicles.
- RFID-enabled smart bins integrated with the municipal IoT platform: A citywide digital platform with waste as its flagship use case before expanding to include other city services.
- Solar-powered self-compacting bins.
- AI sorting and robotics.

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About the integrated platforms

With the shift to private contractors came the need for significant coordination. Managing a service of this scale—€300 million annual budget, 4,500 workers, and tens of thousands of containers—requires close collaboration with these contractors, including CLD, Urbaser, FCC, and

Box 5.2

### Outsourcing and independent oversight: Critical drivers of digitalization strategy

As part of the ongoing efforts to improve service quality and enhance efficiency, the city decided to outsource all waste management operations to several private sector companies, through performance-based contracts. This created a need for an integrated platform to manage contractors and ensure that all associated data would flow to a centralized location.

In addition, inspired by the experiences of the city's other industrial systems, the city saw the value in third-party oversight of the contractors, to monitor performance and ensure quality service delivery.

This created the need for a quality control platform, used by the third-party providers, to monitor performance close-to real time, which allows for rapid response in the event of a problem.

Valoriza, as well as the need to collect accurate data to track contractor performance and coordinate services.

### Municipal platform

To manage this large-scale service, Barcelona implemented Sentilo, a municipal digital platform for a range of city services, including waste and cleaning, connected to the CityOS big data environment. The municipal platform:

- **Integrates data** from sensors installed on containers and vehicles, GPS tracking of fleets, and operational information provided by contractors.
- **Consolidates data** on routes, assets, service execution and incidents in a single system.

### Municipal platform results and outcomes

This approach has contributed to Barcelona's excellent results in keeping the city clean.<sup>10</sup>

The platform gives the city the ability to monitor service delivery in near real time, calculate performance indicators, trace route modifications and incidents through georeferenced records, and adjust operational parameters such as collection frequencies or routes when needed.

By improving data integration and analytics, the platform strengthens transparency, supports contract management and certification processes, and enables more efficient planning and budget control for the city's waste management services.

### Quality control platform

In bringing on third-party providers to monitor contractors' performance, the city implemented a separate—but integrated—platform to manage contracts and quality control:

- Tasks such as route completion by trucks are automatically controlled using GPS and RFID.
- Contractors in every area of the city in charge of waste collection and street cleaning are digitally monitored.
- Third-party inspectors use an app to record observations and verify service delivery, integrating the data with city systems, allowing real-time data upload and analysis.

The approach allows digital verification of the services to activate contract payments (certification) and is opening the path for future contract performance models. The strong digital focus on quality control ensures that contractors meet performance standards while allowing the city to adjust services flexibly as needs change. It has enabled greater transparency, improved efficiency, and easier compliance, along with flexible resource allocation.

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One city within the wider Barcelona metropolitan area has adopted a stricter performance-based model (including applying penalties if performance metrics are not met), with similar digital governance. Reported data indicates that such a model provides the financial levers to cover the cost of the performance-based approach and ensure service quality:

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**Contract:** €10–15 million annual outsourced waste and cleaning contract.

.....

**Performance link:** About 3–5 percent of payments are tied to performance.

.....

**Cost of digital quality assurance /control/governance layer:** About 1–2 percent of the overall service value.

.....

**Benefit from detecting missed or substandard services and applying withheld variable payments or penalties:** About 1–2 percent in annual invoice adjustments, estimated at about €100,000–€300,000 per year.

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The costs for this type of quality assurance system are determined by city size, number of assets managed (bins, trucks, vehicles), and inspection staff needs. This information also feeds into determinations about service / performance penalties in contract negotiations.

## Other digital tools deployed by the city

### Pneumatic waste collection system

Initially implemented in the Olympic Village in 1992, pneumatic waste collection has now replaced traditional waste collection systems in other areas. This expansion involved retrofits throughout existing neighborhoods.<sup>11</sup>

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The collection boxes, developed by Envac, use pneumatic technology to transport waste underground from dense urban areas to centralized collection stations. These pneumatic collection points collect organic and residual waste fractions separately.

The system uses sensors in waste collection inlets to monitor remaining capacity and trigger waste transfer to a central collection point when full. QR codes on the inlets allow the public to submit service requests and report issues. For most households and businesses, the primary model of collection is open bins in the street for five waste categories, placed throughout the city.

In some areas, the city has deployed a network of access-controlled communal smart bins.

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### Results

- The current pneumatic system now serves approximately 50,000 homes and shops, benefiting around 200,000 people.
- Reduced traffic, lower emissions, and less noise pollution due to fewer refuse vehicle movements, particularly in densely populated and tourist-heavy areas.
- Costs: The total cost of Barcelona's automated waste collection system is not publicly disclosed. However, the city has allocated €2.3 million to replace 221 pneumatic collection inlets currently in poor condition due to material corrosion.<sup>12</sup>

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### Smart bins

All smart bin sensor data flows into Sentilo, Barcelona's open-source IoT platform, which uses this information to monitor collection routes, pickups, and open the path for future optimization to eliminate unnecessary trips, making waste management more efficient and sustainable.<sup>13</sup>

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## Results

- Fewer bin overflows
- Improved city hygiene
- Reduction in vermin/pests
- Cleaner and more pleasant urban environment

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## Costs

- Access-controlled bin plus installation: About €500–€1,200 per container.
- Maintenance: €120–€200 per container per year, or about €10–€18 per month per container. Maintenance of more advanced setups, for example, with cameras, weighing, and extra sensors, can range between €200 and €300 per container per year.

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In 2022, Barcelona introduced 15 smart bins for organic waste collection in Sant Andreu del Palomar to add greater flexibility in the collection of organic waste. To encourage participation, residents in the area receive a 30 percent tax discount if they deposit organic waste regularly (at least 40 times a year).<sup>14</sup> Access to the bins is tracked using RFID key chains. When citizens deposit the waste, they scan the keychain, which enables access. The data appears in an app, which also indicates the household's rate of correct organic waste disposal and provides updates.

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## Results

- Incentivized compliance and participation
- Improved separation and treatment of bio-waste

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## Solar-powered self-compacting bins

Barcelona piloted 10 solar-powered, self-compacting bins in Ciutat Vella in 2023, as part of a city-wide clean up strategy.<sup>15</sup> The goal was to reorient the work of municipal services instead of increasing the budget or staff. The

self-compacting mechanism can increase the capacity of a standard bin by up to five times and features a smart alert when the bin is nearly full.<sup>16</sup>

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## Results after the first six months of the pilot

- Fewer collection trips.
- Reduced emptying costs: Eight times less than for traditional bins due to higher capacity and smart-alert systems.
- Scale up: Based on the pilot's success, the city rolled out an additional 15 self-compacting bins.<sup>17</sup>

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## AI sorting and robotics

Further down the waste value chain, the innovative EcoPark treatment center uses AI sorting and robotics within the waste treatment processes. This facility sorts mixed general waste for anaerobic digestion and incineration.

## Next steps

Barcelona's waste management digitalization journey continues, as the city explores new technologies to further enhance its operations. Among the tools:

**AI-equipped smart recycling:** In 2025, Barcelona announced plans to introduce smart recycling containers equipped with AI for automatic waste sorting, though these have not yet been deployed.<sup>18</sup>

**Digital twin:** Barcelona is also making use of a digital twin city model as a tool for innovation, although not for daily operational management of waste systems. The model creates a virtual replica of the city by integrating data from various sensors, allowing planners to test new operational initiatives in a safe, simulated environment before real-world implementation. This enables early identification and resolution of inefficiencies or pain points, ensuring that any new initiative is as effective as possible from the outset.

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## Lessons learned

- **Strong governance and institutional alignment matter.** Digitalization succeeds when embedded within financial, operational, and social systems, with clear leadership and alignment between policy, service delivery, and technology adoption. Integrating data from operational systems such as fleets, assets, and service activities enables more reliable monitoring of service delivery and a new digital governance of city services.
- **Integrated financial and operational planning is key.** Digital tools must support service planning, budgeting, and performance management rather than operate as standalone technical solutions. Integrating data from operational systems such as fleets, assets, and service activities enables more reliable monitoring of service delivery.
- **Robust data management is an important aspect of core infrastructure.** High-quality data systems, including digital inspections and algorithm-driven checks, enable interoperability, performance monitoring, and continued public ownership of operational data. This approach also requires coordinating different digital systems and technologies within a common architecture.
- **Interoperability and modular system design will optimize outcomes.** Managing waste systems as interconnected components allows flexibility in contracting, supports performance-based management, and reduces vendor lock-in. Achieving this requires coordinating multiple digital systems and strengthening collaboration between operational teams, ICT departments, and service providers.
- **Procurement and contracting should be adaptable and flexible.** Contracts must allow for technology updates, iterative deployment, and innovation. Early rigidity in contracting can slow improvement and limit system evolution.
- **Citizen and business engagement must underpin initiatives.** Participation and behavior change are critical to improving separation at source, service uptake, and system effectiveness. Digital engagement tools can support incentives and accountability.
- **Pilots and iterative approaches enable context-aware planning and experimentation.** This allows cities to adapt solutions to local conditions and scale successful interventions over time. These processes also help build digital capabilities within municipal teams and support gradual organizational change.

## Takeaways for other cities

Barcelona's experience shows that financial and environmental gains emerge when digital technologies are combined with strong governance, data capability, stakeholder engagement, and a long-term commitment to circular economy goals.

It also demonstrates how digital platforms can strengthen waste and cleaning services governance with transparency, operational oversight, and evidence-based decision making.

# Battambang, Cambodia

## Digital platform for improved fee collection and accountability

### The waste challenge



Systemic waste sector deficiencies



Uncollected waste polluted streets and waterways



Low environmental awareness



Low service/low revenue trap = inadequate funds for improvements

### The digital solutions

Mobile app for schedules and bills

GPS tracking for route optimization



Digital billing + mobile payments

Sponsored by LUMA for 1 year; now city-funded

### Results

Increase in household collection coverage:



**Digital tools** boost revenue and reliability



**Improved compliance** through live fee tracking

### Takeaways



**Baseline assessment** should guide design



**Strong and consistent enforcement measures** needed

#### Essentials

Baseline assessment to diagnose issues and identify solutions





Mobile connectivity

Training /public engagement and education

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**Prior to 2018, residents of Battambang, Cambodia's third-largest city, had low environmental awareness. Plastic pollution was a growing concern, but citizens lacked both knowledge and motivation to engage in sustainable practices. Uncollected waste accumulated on streets and in rivers, eventually flowing into Lake Tonle Sap, causing serious environmental problems.**

Systemic challenges within Battambang's waste sector compounded the problem:

-  **Fragmentation:** Limited coordination between actors in the waste sector.
-  **Poor service and service coverage:** Waste collections were unreliable and insufficient, with only about 40 percent of households in the city receiving a solid waste service.
-  **Financial limitations:** Dissatisfied residents were unwilling to pay for inadequate services, leading to a low-service, low-revenue trap. This, in turn, left the city without the funds needed to improve operations or pay workers fairly.<sup>19</sup>
-  **Weak enforcement:** Fee collections lacked effective enforcement mechanisms.

These issues created an urgent need for reform and the adoption of innovative solutions to break the cycle and restore public trust in waste management services. To enhance the city's public image, the Battambang City Administration sought to regain control over waste management services. In particular, city administrators looked to improve waste-fee collection, which was managed by private collection companies.

### **Digital solution: Solid waste management platform**

To improve management across the waste sector, the city initiated the Battambang Smart Solid Waste Financial

Management project in 2021. The project began with a baseline analysis, to gain a comprehensive understanding of the current solid waste management system and identify barriers to improvement. This process, supported by the ASEAN Australian Smart City Trust Fund, involved data collection, field visits, and stakeholder engagement. The analysis highlighted critical needs, including digital payment solutions, incentives to improve fee compliance, and greater public awareness and motivation for waste management.<sup>20</sup>

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### **Emerging from this process: The identification of a digital waste platform as a solution.**

Developed by LUMA System—a Cambodian software company specializing in smart cities solutions—the platform was designed to modernize waste management processes, increase citizen engagement, and improve the financial management of the waste collection service. Adopted in 2023, the platform features:



**Mobile app:** Residents can check collection schedules and view bills, making service information easily accessible.



**Digital billing and payment system:** Real-time monitoring of payment compliance improves transparency and financial accountability.



**GPS tracking of collection vehicles:** Route mapping and schedule optimization ensure timely and efficient collections.<sup>21</sup>

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LUMA sponsored the platform for its first year in operation, providing a strong foundation for its adoption. Today, the city pays a monthly fee for use of the platform.

## Results and outcomes

The introduction of the LUMA digital waste management platform has streamlined both operational and financial aspects of waste management in Battambang. With the digital platform, the city now actively monitors operations through GPS-enabled tracking, ensuring greater coverage, responsiveness, and collection efficiency.

### Outcomes for Battambang residents

- More reliable collection services: Coverage has increased from about 40 percent of households to 75–80 percent, and service is more consistent.<sup>22</sup>
- Simplified payments: Convenient options include bank transfers and integrated apps, eliminating the need for cash collection.
- Increased satisfaction and greater trust in the system.

### Outcomes for the city of Battambang

- Improved payment compliance: Previously, the city played a minimal role in fee collection, leaving households to pay collection companies directly, often irregularly, leading to missed payments and poor service. Now, the platform issues monthly invoices, tracks payment status in real time, and generates reports.
- Reduced administrative burden: The digital platform replaces manual processes.
- More predictable revenue streams and strengthened accountability across the system: Although the system has greatly improved fee collection and boosted revenue, full financial sustainability remains a work in progress. Efforts are underway to align fee structures and operational costs to ensure long-term stability.

#### Box 5.3

### In their own words: What Battambang stakeholders say about the digital waste management platform



#### On waste collection:

*"For sure [waste collection] has improved... now when there is a waste crisis, the city responds and informs the collection company."*



#### On payment compliance:

*"The app can follow up where the household has paid or not yet paid... and they also have reports from the app."*



#### On citizen convenience and satisfaction:

*"The household... can pay directly by the app or to a bank."*

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## Lessons learned

- **The LUMA system plays a critical role in supporting the city government** by providing a more efficient system for waste management and fee collection. Residents now take more personal responsibility to dispose of waste in ways that minimize environmental impact.
- **Public education has been central to the platform's success**, ensuring widespread understanding and adoption: Early and sustained community engagement—through workshops, open discussions, and social media outreach—helps build momentum and maintain participation.
- **Financial sustainability remains a challenge:** Service fees currently fall short of covering operational and digital system costs.
- **Strengthening and consistently using enforcement measures** could help to preserve best practices and address current deficiencies.

## Takeaways for other cities

Battambang's experience shows that digital waste management platforms and billing systems can help waste companies improve their fee collection and increase their revenue.

- Conducting a baseline or readiness assessment was essential for Battambang to identify capacity gaps, diagnose issues, and select effective solutions.
- Successful adoption of digital tools for waste management depends on several enabling factors: Battambang's transformation has been driven by a culture of innovation, inclusive governance, and strong local leadership, supported by trusted intermediaries and international partnerships.<sup>23</sup>
- For scalability to other towns in the Tonle Sap Basin and beyond, digital platforms will require mobile connectivity, training programs, and public engagement.

## 📍 Chengdu & Suzhou, China

*Smart systems to improve waste sorting, collection, logistics and recycling*

### The waste challenge



Rapidly urbanizing cities with extensive construction



Illegal construction waste dumping



Significant dust pollution problem



Fragmented waste sector oversight and lack of real-time monitoring

### The digital solutions

AI-powered smart bins with WeChat integration



GPS trajectory tracking for 16,000 trucks



Machine learning to classify earthwork-related locations (ERLS)



Centralized sorting center with IoT-enabled tracking



### Results



38

cities reached in Chengdu, with 31,500 smart machines (2024)

5% ↗ 40%

increase in Suzhou's food waste separation



98%

sorting accuracy achieved

15,377 T

of plastic diverted since inception

### Takeaways



Combining GPS with machine learning delivers actionable insights.



Approach has high scalability potential for other cities.

#### Key requirements

Strong data governance

Connectivity

Early investment, including in analytics and staff training

Inter-operability standards

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**In 2019, as part of its “Internet Plus Recycling” strategy, China made waste separation mandatory for its major cities. China’s fourteenth five-year plan (2021-2025) built on this requirement by setting targets for nearly 300 cities. Targets included implementing sorting solutions by 2025, and recycling 60 percent of all waste.<sup>24</sup> These measures were designed to support the country’s broader circular economy objectives and its Zero-Waste City initiative, aimed at reducing urban waste.<sup>25</sup> As megacities with over 20 million residents, Chengdu and Suzhou needed scalable solutions to manage large volumes of waste and drive public participation to comply with the stricter national waste sorting mandates. In addition, rapid urbanization has contributed to challenges such as illegal construction waste dumping and associated dust pollution in cities such as Chengdu and Suzhou.<sup>26</sup>**

Chengdu’s LOVERE project, launched in 2019 in response to the new waste separation requirement, aimed to leverage digital technology to improve recycling rates and reduce contamination through citizen engagement.

Suzhou focused on building a comprehensive digital platform to manage the entire waste value chain and align with the Zero-Waste City initiative. Prior to 2020, the city had a 5 percent food separation rate and overall citizen engagement with recycling was below 2 percent.

### **The digital solutions: Smart bins and connected platforms**

The LOVERE initiative was first implemented in Chengdu and Xi’an, with smart bins as the centerpiece of the program. These bins help citizens separate their non-organic waste by using AI-powered cameras that scan materials and reward recyclers with WeChat credits—micropayment rewards in the popular WeChat super-app that includes messaging, social media and payments. If a resident makes an incorrect deposit, LOVERE can follow up via their WeChat account to explain which items the system can accept. In addition,

residents can check the fill status of each bin through WeChat, helping them decide the best time and location to drop off their recyclables.<sup>27</sup>

Collectors are notified through IoT when bins are 80 percent full. Field workers are then dispatched. They follow an optimized route to the bin for emptying within 30 minutes.<sup>28</sup> This system ensures a 24-hour self-recycling service for residents. LOVERE also opened the Chengdu LOVERE sorting center in 2023 to complement the smart bin network. The operational process follows a “point-station-center” model. First, recyclables are deposited in smart bins. Next, they are transported to transfer stations. Finally, they are sorted at centralized facilities.

The processed materials are sold to recycling enterprises, creating a closed-loop system that advances circular-economy objectives. The sorting center uses a semi-automatic sorting line complemented with AI-powered sorting technology to quickly sort materials by weight and shape into up to 80 individual streams.

The technology combines image recognition, cloud computing, and automated controls to detect items like plastic bottles, milk cartons, and cans. The center is also integrated with IoT for real-time tracking of material flow and contamination rates. Each rubbish bag has a QR code, which enables traceability throughout the process. It also helps capture household waste delivery data for each bin, such as proportions of materials and user demographics and behavioral characteristics.

The data is used to provide insights for management and to help inform policy. All data is centralized within a digital management platform, which oversees and coordinates the collection and treatment processes.

To address illegal construction waste dumping in Chengdu, machine learning models were used to assess GPS trajectory data for more than 16,000 construction waste hauling trucks, along with information about each site’s location. The results showed almost 80 percent accuracy in correctly identifying site types. The models successfully identified 724

dumping sites, 48 concrete mixing stations, and 80 truck parking locations, enabling the local authority to effectively manage urban dust pollution at low personnel costs.

Similarly, Suzhou operates a government-funded digital platform that enables management of the entire waste value chain—from collection to treatment. Waste management companies also use the platform to oversee their fleets and optimize collection routes. Data from approximately 15,000 smart collection points, each with unique QR codes, flow into the platform via IoT for real-time analysis, allowing precise tracking of participation and waste generation. The platform is fully government-funded, purchased through a one-off payment, with periodic upgrades also financed by the government. Beyond operational management, the platform supports online trading of recyclables and facilitates payment and fee collection.

To drive community engagement, government-developed apps promote waste separation at source through educational programs and recycling videos. These apps address initial reluctance among residents to adopt the new system. Additional apps allow residents to schedule doorstep recycling collections and earn reward points redeemable for gifts and other incentives.

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## Results and outcomes

### LOVERE program

- In Chengdu and Xi'an, WeChat incentives and awareness campaigns engaged more than 393,000 residents through the LOVERE program in 2024, helping divert 5,778 tonnes of plastic waste that year and 15,377 tonnes since inception.<sup>29</sup>

- LOVERE's AI image recognition achieves over 98 percent sorting accuracy, surpassing traditional sorting methods and enables recycling of 90 percent of collected materials.<sup>30</sup>
- The model has scaled to 38 cities in 2024, up from 35 in 2023, with a nationwide network of 31,500 intelligent recycling machines—an increase from 21,038 units in 2023.<sup>31</sup>
- The number of installed bins in Chengdu and Xi'an rose from 1,400 in 2021 to 3,007 in 2024.<sup>32</sup>
- While city-specific data for Chengdu is limited, national figures show strong progress. User numbers in China have grown by 7 million between 2023 and 2024, rising from 15 million in 2023 to 22 million in 2024. The annual recycling volume in 2024 reached 679,000 tons, representing a 67 percent increase from 406,300 tons in 2023.<sup>33</sup>
- Looking ahead, the next steps involve developing a business-to-business model to engage office and commercial businesses.

### Suzhou's digital platform

Suzhou's platform has increased food waste separation from 5 percent to 40 percent. Despite initial resistance, residents are now more willing to separate waste and engage with the system.

- Participation and sorting accuracy across food, recycling, and general waste is now nearly universal at close to 100 percent.
- Waste remains separated throughout transportation—no mixing occurs on collection vehicles.
- Citizen satisfaction has improved significantly.
- Daily collection is consistent.

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## Lessons learned

The experiences of Chengdu and Suzhou demonstrate that when all elements converge in the right ways, digital tools can transform waste management into a high-performing data-driven ecosystem.

- **Digital transformation succeeds** when technology, governance and community engagement align. Government backing, and clear policy direction created the foundation, while smart technology amplified impact.
- **Mandatory food waste separation** acted as a key enabler, ensuring compliance and driving behavioral change.
- **Changing consumer habits proved difficult**, but progress came through behavioral incentives, such as micropayment credits and gamified apps, combined with gradual implementation to encourage adoption. Initial resistance in Suzhou (due to higher operational fees paid by citizens to waste companies) was addressed through proactive education and engagement.
- **Robust data management and security are critical**. Initially, it was challenging to standardize data from multiple companies, but the effort was essential in achieving operational efficiency and accurate analytics.

## Takeaways for other cities

- Cities considering similar solutions should prioritize governance, infrastructure, and public engagement.
- Early government investment is important, and technical standards should be defined upfront to avoid data fragmentation and ensure interoperability.
- Public education campaigns and behavioral nudges should run in parallel with tool deployment, as correct sorting at source is key to overall success.
- Gamification and mobile apps can sustain engagement, while phased upgrades keep systems current.
- Operational aspects such as hardware maintenance, and strategies for continuous improvement should be incorporated.



# Cotonou, Benin

## Digitalization for cleaner city, jobs, & economic opportunity

### The waste challenge



Overflowing waste containers



Low rates of separation at source



Limited recycling infrastructure



High needs for income generation



Strong governmental pressure to clean up the city



Fragmented operations



Need to address goals of municipal circular economy

### The digital solutions

Mobile billing and payment platforms to ensure secure transactions



Coordinated systems, with one central operator, to replace fragmented ops



GPS tracking and mobile apps for field workers to optimize routes and to ensure accountability



Market apps that connect collectors with recyclers

### Results



Streamlined and improved collections



**500**

fewer landfill trips; reduced fuel consumption and carbon emissions

#### Improved citizen satisfaction:

- More reliable service provision
- Convenient, secure, online billing

#### Marketplace transparency and accountability:

- Reduced informal practices
- Business and job creation
- Income generation

### Takeaways



**Integrating technology** with social goals drives adoption.



**Technology alone** cannot overcome systemic inefficiencies.

#### Key requirements

Basic digital infrastructure

Mobile connectivity

Strong collaboration among stakeholders

Institutional capacity building

Public awareness campaigns to drive behavior change

Financial models that balance cost recovery with affordability

**Cotonou is Benin's largest city. For years, its waste management system was characterized by inefficiencies and environmental hazards. The Greater Nokoué region generated 607,000 tonnes of household waste annually, much of it deposited in uncontrolled sites.<sup>34</sup> Recycling rates were negligible, and source separation was virtually absent, leaving organic and recyclable fractions mixed with general waste.<sup>35</sup> Rapid urbanization compounded these challenges, overwhelming municipal services and creating public health risks.**

Several studies had identified the severity of the problem:

- **Five out of 15 regrouping points**—temporary waste transfer stations—were non-functional.
- **85% of waste was theoretically recoverable** but remained untreated.
- **Overflowing containers, irregular collection schedules, informal dumping, and fuel theft** from collection vehicles were common.

The findings underscored the need for systemic reform. The government set out a mandate to clean up the city, with a strong emphasis on improving waste collection and sanitation.

### Digital solution: Integrated waste management

In 2019, the government took a decisive step toward addressing the issue in a comprehensive manner with the launch of the Greater Nokoué Solid Waste Modernization Project, financed through the Clean Oceans Initiative Grand Nokoué Benin. An initial pilot project, funded by the French government, served as a baseline assessment to understand the current state of waste collection in Cotonou and to showcase potential improvements. This was followed by the creation of Société de Gestion des Déchets et de la Salubrité (SGDS) in 2020, which replaced fragmented municipal and nongovernmental-led systems with a centralized operator.<sup>36</sup>

SGDS also introduced a fee-for-service model with digital billing and online payment systems, ending decades of free collection. As part of the modernization effort, the city also upgraded and enhanced its collection services.

### About the billing and payment system

Among the billing and payment system's digital components:

**Online invoicing and payment systems:** To reduce reliance on cash transactions and improve revenue collection.

**Mobile platforms:** For service requests, route planning, and compliance monitoring.

**Integration of digital ID frameworks:** For secure transactions and accountability.

#### Box 5.4

### Cotonou's strategic shift from free collection to fee-for-service: How they did it

Using electricity connections as a proxy, pre-collection mapping identified households that were most likely to have the ability to pay.

This data informed a policy decision to link waste collection fees to electricity bills, although payments are processed separately through an online system.

As the improvements in waste collection became apparent, more households were willing to pay.

The changes have strengthened financial sustainability and improved cost recovery.

### About the collection service modernization

To support improved service collection, the city purchased a fleet of 100 new collection vehicles and motorcycles, enabled by financing from Bpifrance, a French development finance institution.

In addition to building a more modern fleet, the city sought to optimize waste collection by installing GPS tracking equipment. Purchased from technology supplier Simplifici SAS for an initial, one-time cost of about €400 per vehicle, the hardware also comes with a monthly subscription fee of about €20 for each piece of equipment.<sup>37</sup> The tracking solution includes:

**Mobile apps** for field controllers to report container status with photos and geolocation.

**Online platform** with route optimization tools to design and monitor collection circuits.

**RFID/Near-field communication (NFC) tags** for container verification.

**Vehicle telematics** to monitor fuel consumption and carbon footprint.

### Current status

After a pilot to assess feasibility and gather insights, the city rolled out the digital tool systems more widely. They are now integrated as a mainstream aspect of Cotonou's waste management system, enabling real-time monitoring, KPI reporting, and billing integration.

Physical upgrades such as sorting and composting facilities complement these digital systems. However, the core innovation lies in digitizing operations, workflows and financial processes to create a more efficient, transparent, and scalable waste management model.

As of January 2025, households pay waste collection fees ranging from 3,000 to 30,000 West African CFA francs (approximately \$5.30–\$53.60) per month, depending on service level. Payments are processed online within 15 days of service consumption, a move designed to improve cost recovery and transparency.<sup>38</sup>

### Next steps

While IoT-enabled monitoring and advanced analytics are not yet fully deployed, feasibility studies for energy recovery and anaerobic digestion are planned, signaling a shift toward smart, sensor-driven operations.<sup>39</sup>

### Results and outcomes

The digital transformation in Cotonou has delivered measurable improvements in efficiency, sustainability, and financial viability.

Among the results: A major increase in waste collection volume and reduction in landfill trips.

Operational data provided by a stakeholder shows that in 2024, of the approximately 607,000 tonnes of waste generated, 430,000 tonnes of waste were collected.

In 2025, this increased to an estimated 470,000 tonnes collected, while number of landfill trips dropped by 500, despite higher volumes.

Optimized routes and real-time operational control have yielded:

- Improved service reliability.
- More residents willing to pay for quality waste management.
- Significant reductions in kilometers driven, fuel consumed, and carbon emitted.
- Lower maintenance costs and less fuel theft.
- Full transparency and accountability, enabling supervisors and managers to monitor completion rates and control routes in real time.

- Reduction in informal practices, such as incidents of drivers demanding unauthorized payment to collect waste.
- Improved trust across the value chain.

Despite some ongoing operational challenges, Cotonou is now recognized as one of Africa's cleanest cities, showcased for visiting delegations as a model to replicate.

## Lessons learned

Cotonou's modernization journey yields important insights:

- **Institutional reform and digitalization should go hand in hand:** Technology alone cannot overcome systemic inefficiencies without governance capacity and accountability mechanisms. The creation of SGDS provided a single point of responsibility, enabling the rollout of digital billing and compliance systems.
- **Cost recovery through household fees is essential for sustainability,** but it requires strong public engagement to avoid resistance and ensure equitable access.
- **Local adaptation is essential:** Solutions should fit the local infrastructure, vehicle types, and socioeconomic context. In Cotonou, the focus on adapting the system to local conditions yielded significant cost savings. The city was able to avoid purchasing costly sensors by relying instead on smartphones for data entry and communication.
- **Pilot studies before full rollout proved invaluable for tailoring the digital solution to the local context.** For Cotonou, the pilot uncovered hidden inefficiencies and issues, such as overloaded tricycles that quickly broke down, prompting a shift to larger, more suitable vehicles. Such unanticipated challenges highlight the need for flexibility and iterative improvement.
- **Modernization is not just a technical exercise:** It requires significant household behavior change, particularly in source separation and sanitation practices.

## Takeaways for other cities


Cities seeking to replicate Cotonou's approach should consider several prerequisites:

- Customization is critical and solutions should align with local infrastructure and socio-economic conditions.
- Basic digital infrastructure and mobile connectivity are essential for implementing online billing and compliance systems.
- Long-term sustainability depends on financing models that maintain operations after donor support ends.
- Institutional capacity building is equally important. Without trained personnel to manage digital platforms and enforce standards, technology investments risk underperformance.
- Public awareness campaigns should accompany infrastructure upgrades to drive participation in source separation and fee payment.
- Financial models should balance cost recovery with affordability, ensuring that modernization does not exclude vulnerable households.

# 📍 Seoul, Republic of Korea


## Enhancing the PAYT system with RFID

### The waste challenge

 High-density city with mandatory food waste separation but low rate of compliance

 Overflowing public bins

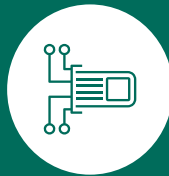
 City-center issues with odor and pests

 PAYT system reliance on pay-per-bag incentivized households to delay disposal to maximize bag value

### The digital solutions



RFID pay-by-weight food waste machines to discourage delaying disposal until bags are full



Smart card-enabled for instant disposal

### Results



~ **98%**

food waste recycling 10 years since introduction



~ **30%**

reduction in food waste associated with RFID



**IMPROVED**

PAYT system convenience and fairness

### Takeaways



**With PAYT system**, convenience drives compliance.



**Weight-based charging** is perceived as fairer than bag based systems.



**Trusted digital platforms** support large scale adoption.

### Approach

Most effective in established PAYT systems

Best-suited to high-density cities


Gateway to future incentives for food waste reduction

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**In the 1990s, Seoul faced mounting waste management challenges due to rapid urbanization and high population density. Food waste was a major issue, given that only 2 percent was recycled. The city collected waste four to five times a day. And yet, in the densely populated city center, public bins constantly overflowed.<sup>40</sup> This large volume of organic waste in such a densely populated setting led to persistent pest and odor problems.**

To tackle this growing food waste problem, Seoul introduced a “pay-as-you-throw” (PAYT) system, which charged households per bag of waste. But the initiative, aimed at increasing accountability for waste generation, led to unintended consequences:

 **Fee avoidance:** Residents would discard their household waste in public general waste bins.<sup>41</sup>

 **Unfair billing:** Households were charged by the bag, rather than for the actual weight of waste they were producing.

### **The digital solution: Food waste tracking and smart bins**

To address these issues, Seoul focused on improving food waste tracking, running a pilot of RFID-based tools. The pilot involved:

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**Integrating an RFID-based food waste weight-based system** into the city’s PAYT model.

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**Distributing RFID-equipped smart bins** that precisely track and bill by household.

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After the pilot demonstrated efficacy, Seoul implemented the system city-wide. A separate pilot of smart street bins for general waste, called “Clean Cubes,” did not result in full-scale implementation.

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### **Results and outcomes**

The RFID-based food waste weight-based system is part of a significant transformation in the Republic of Korea’s food waste management.

- Food waste recycling diverted from residual waste increased from about 2 percent in the 1990s to 98 percent in 2023.<sup>42</sup>
- The amount of food waste generated in Seoul fell by about 10 percent between 2013 and 2019. After an increase in 2020 and 2021, the amounts generated dropped back to 2019 levels in 2023.<sup>43</sup>
- Previously, waste fees were shared equally among residents or charged by bag volume. The precise weighing system incentivizes behavior change as individual households reduce their food waste at source to lower their specific bills.

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### **Cost-benefit analysis**

Purchase and installation of a single RFID system that can serve around 60 households with an 8-year lifespan costs about 2,000,000 South Korean won (about \$1350), compared to 50,000 South Korean won (about \$35) for a standard food collection bin.

Initially, the upfront costs were shared, with the central government covering 50 percent, the city of Seoul covering 30 percent, and the autonomous district covering 20 percent. Recently, this split has changed, with the city covering 35 percent of costs and the autonomous district covering 65 percent.

To quantify the benefits, the following assumptions were used:

- The RFID system reduces food waste generation by about 30 percent, according to figures provided by a stakeholder with knowledge of the system.

- 90 kilograms of daily food waste deposited per bin before a machine is installed.
- Food waste treatment cost of 200,000 South Korean won (about \$135) per ton.
- Over the 8-year lifespan of the RFID-equipped bin, this yields savings of 13,818,000 South Korean won (about \$9,400) and a return on investment of over 700 percent.

### The analysis revealed:

- The 30 percent reduction in food waste generation enabled by the system lowers food waste treatment costs enough to cover the cost of an RFID-equipped bin in one year.

Note that this simple calculation does not account for any loss of fees from the general waste PAYT system (from which food waste is diverted) or the operating and maintenance costs of the RFID bins.

### Lessons learned

**Using weight-based systems combined with RFID technology for accountability and tracking** provides a strong incentive for individuals to reduce their waste generation at source.

### Takeaways for other cities

- The success of Seoul's RFID-based solution should be understood within the context of the Republic of Korea's widely deployed and accepted PAYT system. Residents are accustomed to paying for waste services by weight or volume. Similarly, RFID equipped IoT systems connected to billing are suited to Seoul, given its strong internet infrastructure, extensive connectivity, and high-density living.
- The initial pilot of 85 Clean Cubes showed promise. Among the results:
  - 66 percent reduction in collection frequency,
  - 83 percent reduction in collection costs.
  - Increase in the recycling diversion rate to 46 percent.
  - Elimination of waste overflow.<sup>44</sup>
- Why did the city decide not to scale up the Clean Cubes solution following the pilot? One stakeholder noted that the initial rollout was conducted in busy tourist areas, where frequent clean operations proved challenging. In addition, fragmented contracting, involving 4-5 private waste management companies for each of Seoul's 25 autonomous districts, posed a barrier to a unified, city-wide platform. Since the pilot, the city has added to its public waste bin inventory with traditional bins, rather than smart bins.<sup>45</sup>

## Section 6

# Conclusions and recommendations

**Digitalization is reshaping waste management, turning traditional systems into data-driven, efficient, and sustainable operations. When combined with strong governance and inclusive strategies, it enables municipalities and waste management companies to achieve systemic change and accelerate progress toward circular-economy goals.**

While municipalities and waste management companies in high-income contexts can typically leverage advanced integrated systems, those in lower-income contexts can achieve rapid gains through foundational solutions and phased implementation strategies. Across all settings, interoperability, modularity, and adaptability should be built in from the start to future-proof investments.

Engagement of citizens and businesses drives system performance, and digital tools are most effective when paired with behavior change initiatives targeting both households and commercial waste generators. Information tools, incentives, and feedback mechanisms increase participation in source separation, improve compliance, and raise material quality, reducing contamination across the system.

Figure 6.1

## Recommendations for municipalities and waste management companies

### Set objectives & select tools



- Define clear strategic objectives for digital transformation consistent with and aligned to operational realities.
- Select tools that support the goals.



- Select digital tools aligned with operational priorities, such as route optimization or automated reporting.

### Assess current systems



- Conduct objective and honest city wide infrastructure and connectivity assessments.



- Conduct technical audits to understand legacy systems and integration needs.

● Municipalities ● Waste management companies

## Recommendations

The shift to digital waste management works best when both municipalities and waste management companies follow a few simple, practical steps.

Clear objectives and system assessments should guide tool selection. Staff readiness and pilots that validate positive results through measurement support smooth rollout. Only then can teams focus on vendor performance, KPIs, data use and improving user experience. This reduces risk and ensures digital tools deliver real benefits. Figure 6.1 offers recommendations for both.

Ultimately, digitalization offers a practical, scalable pathway to transform waste management into a driver of circularity and sustainability. By combining technology with governance, engagement, and inclusive strategies, municipalities and waste management companies can move from incremental improvements to systemic change—delivering environmental, social, and economic benefits for decades to come.

### Plan for scalability



- Plan for system scalability to expand to new zones or requirements, including understanding the costs and returns of pilots and city-wide application.



- Adopt modular, scalable systems allowing features to be added over time.

### Build staff capacity



- Support capacity building for municipal staff through training and digital literacy initiatives.



- Invest in staff training and upskilling for crews, supervisors and IT teams.

### Test before scaling



- Engage waste companies early to validate feasibility.



- Participate actively in pilot programs before full rollout.

### Manage vendors



- Set procurement requirements for data ownership, interoperability, cybersecurity and vendor accountability.



- Work with vendors to secure strong service-level agreements with clear support pathways.

### Set key performance indicators (KPIs)



- Embed digital expectations in contracts.
- Set trackable KPIs to justify scaling, using data collected from digital tools for effective oversight.



- Use KPIs to measure performance (fuel savings, missed collections, recycling yields), using data collected by service digitalization.

### Ensure good data practices



- Ensure policy and regulatory alignment, including data protection and service-level standards. Justify scaling, using data collected from digital tools for effective oversight.



- Establish internal governance for data use to support planning and fleet management service digitalization.

### Prioritize ease of use



- Ensure tools and systems are user-friendly for citizens and staff.



- Ensure tools and systems are user-friendly for field conditions (simple interfaces, offline capability).

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# Appendix

## Digitalization tools by category

This appendix provides more detail on digital tools in each of the four categories.



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### *Engagement and behavior change tools*

#### Foundational engagement solutions

Foundational engagement tools are low-complexity, quick-start solutions that provide basic visibility and simple behavior-change prompts, including:

- SMS-based notifications
- WhatsApp or basic messaging-app broadcasts
- Bulk email alerts

#### **The problem that needs addressing**

Limited public understanding of proper disposal practices leads to poor compliance, illegal dumping, and inefficient collection systems. Traditional communication methods such as printed notices often fail to reach all residents, especially in rural or low-literacy areas.

#### **How foundational engagement tools help**

Basic digital citizen engagement strategies use simple, low-cost communication channels to inform, educate, and motivate residents. In addition to SMS alerts, authorities can use WhatsApp or other messaging-app broadcasts to provide service reminders, billing information, and disposal guidance. These channels work well in areas with mixed literacy levels or limited smartphone access. Bulk email alerts may be suitable where email penetration is higher for audiences such as businesses and institutions. These messages can be reinforced through radio announcements and printed notices. Together, these approaches improve awareness of collection schedules, encourage correct disposal practices, and strengthen payment and service compliance without requiring complex digital infrastructure.

#### **Requirements**

This solution requires an SMS-based notification system for billing reminders, waste collection days, and service updates. Additional requirements include:

- Basic customer database to manage phone numbers and message distribution.
- Staff training on community outreach and communication techniques.

## Investment costs and returns

Implementation costs are low when using existing telecom services and community networks, while radio partnerships often require minimal fees or sponsorship arrangements.

Returns on investment are indirect but significant, arising from improved compliance, reduced operational inefficiencies, lower costs associated with illegal dumping, and stronger payment and revenue collection.

### Real-world use case

GREATER PORTO, PORTUGAL: TARGETED DATA-DRIVEN OUTREACH TO INACTIVE HOUSEHOLDS



#### Results

Public awareness increased 26% among previously inactive households in 3 months' time.



#### Takeaway

Targeted communication can swiftly increase participation where systems exist.<sup>46</sup>

## Enhanced engagement solutions

Enhanced engagement tools are higher-impact improvements that use richer data and stronger engagement mechanisms to change behavior at scale, including:

- Mobile apps and web platforms for engagement
- Education dashboards
- Gamification systems

### The problem that needs addressing

Even in digitally mature regions, waste management programs often struggle to achieve high levels of citizen participation in recycling and source segregation. While collection services may be efficient, lack of awareness and motivation among residents leads to contamination of recyclables, low recycling rates, and missed opportunities for resource recovery.

### How enhanced engagement tools help

Mobile applications and web platforms designed for public engagement go beyond basic service access by actively promoting sustainable practices. These tools can provide educational content on proper waste segregation, interactive guides for recycling, and gamified features such as reward points for compliance. Push notifications and email alerts remind users of collection schedules, recycling days, and special campaigns. Web platforms offer similar functionality for users who prefer browsers, enabling easy access without requiring app downloads. Integrated feedback tools allow citizens to report missed collections or suggest improvements. Data collected through these platforms helps operators monitor participation rates and design targeted interventions.

## Real-world use case

### KANSAS CITY, USA: CITY-WIDE DIGITAL WASTE SERVICE INTERFACE



#### Results

Satisfaction up 17%; about \$2 million in savings; expanded coverage to about 500,000 residents.



#### Takeaway

Simple service apps improve trust while lowering operating costs.<sup>47</sup>

## Requirements

- Mobile app (Android/iOS) and responsive web platform with user-friendly interface, potential gamification features such as points, badges, and leaderboards to incentivize participation.
- Feedback and reporting tools for missed collections or service issues
- Data analytics dashboard to track participation, recycling rates, and user engagement.
- Secure backend infrastructure with application programming interfaces (APIs) for interoperability and scalability.

## Real-world use case

### JAKARTA & YOGYAKARTA, INDONESIA: GAMIFIED IOT-ENABLED RECYCLING ENGAGEMENT



#### Results

Smart-bin prototype using ultrasonic and load-cell sensors achieved about 80% detection accuracy, with 100% of users reporting increased motivation from the gamified design.



#### Takeaway

Gamification can validate behavior-change tools at low cost.<sup>48</sup>

## Investment costs and returns

Digital development and running costs vary based on complexity, while adding gamification and analytics features may increase initial investment. Simple apps could cost between \$10,000-\$30,000 to develop, which would include alerts and scheduling, while more moderate apps with in-app payment and API integration could cost \$30,000-\$70,000.<sup>49</sup>

Returns on investment are indirect but can be significant. Data generated through digital tools helps municipalities and waste companies identify where contamination occurs, where services are underused, and where infrastructure or behavior-change interventions will have the greatest impact. This supports more targeted investment in collection services, recycling infrastructure, and engagement programs, reducing landfill costs, improving resource recovery, and strengthening regulatory compliance.



## *Waste collection and logistics tools*

Waste collection and logistics tools support waste collection operations by using real-time data, route optimization, and automated tracking to improve efficiency, reduce costs, and minimize environmental impact. They are aimed at waste management companies looking for options to improve their operational efficiency and monitoring of collection rounds.

### Foundational waste collection solutions

Foundational waste collection and logistics tools represent a low-complexity, quick-start solution to provide basic visibility and improve route design, including:

- GPS-enabled collection vehicles: Basic location/collection round visibility
- GIS-based route planning: Desktop redesign of static routes; scenario tests

#### **The problem that needs addressing**

Waste collection operations often lack visibility in day-to-day activities. So, it is unclear whether vehicles are following pre-agreed routes, or whether collections have been effective and efficient. This lack of transparency can lead to inefficient routing, higher fuel consumption, missed collections, and difficulty in addressing customer complaints. It also can result in route designs that fail to reflect variations in population density, road constraints, or waste-generation patterns.

#### **How the foundational waste collection tools help**

Equipping waste collection vehicles with GPS trackers and basic vehicle telematics enables real-time monitoring of vehicle location, fuel use and driver behavior and route adherence. This helps supervisors verify performance, reduce avoidable fuel burn, and support predictive maintenance.

GIS-based route planning uses geographic data—road networks, service areas, population density, and estimated waste generation—to redesign collection routes. This improves route efficiency, reduces fuel consumption, and ensures more even service coverage. Waste management companies can also model different scenarios and update routes as neighborhoods grow or waste-generation patterns change.

#### **Requirements**

- Cellular connectivity for real-time data transmission
- Data reporting platform to allow review of the collected GPS data: Typically, this is provided by the GPS technology vendor
- Access to GIS data: Including roads, service areas, population density, and waste-generation estimates
- Basic training for operator staff

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## Investment costs and returns on investment

In general, these are subscription-based tools, with charges on a per-vehicle basis. Costs can cover both the hardware and the digital monitoring platform, although some vendors charge hardware separately. Subscription costs vary, depending on the size of fleet. Larger fleets often benefit from lower per-vehicle costs. For example, in the United States, subscription costs might range between \$10 and \$20 per vehicle per month, depending on fleet size. In Cotonou, Benin, the municipality paid around €400 (about \$465) per collection vehicle to install GPS equipment and €20 (about \$23) per month per unit for the Simplificiti platform.<sup>50</sup>

GIS route-planning costs typically involve a one-time software license or annual subscription, plus potential costs for GIS data acquisition. For example, ArcGIS can cost \$700–\$3,800 per year for professional use.<sup>51</sup>

Returns on investment can be rapid—sometimes within months—through reduced fuel use, fewer vehicle hours, and improved round efficiency. Results vary widely depending on baseline performance; some studies show 26 percent less distance traveled and 22 percent less time spent on the road. Other results, such as those reported by Sfax, Tunisia, show far higher savings.<sup>52</sup>

### Real-world use case

COTONOU, BENIN: GPS-ENABLED FLEET MONITORING



#### Results

Fewer missed collections, improved schedule compliance, better fuel control.



#### Takeaway

Basic GPS tracking delivers rapid efficiency gains at low cost.<sup>53</sup>

### Real-world use case

CITÉ EL HABIB, SFAX, TUNISIA: GIS-BASED ROUTE OPTIMIZATION



#### Results

57% reduction in travel time, 40% reduction in distances traveled, 48% reduction in fuel use.



#### Takeaway

Desktop GIS tools can deliver major savings without new hardware.<sup>54</sup>

## Enhanced waste collection solutions

Enhanced tools are characterized by increased integration and can yield greater impact. They use live data and automation to optimize operations and include:

- Vehicle telematics and diagnostics (fuel use, driver behavior, engine health, maintenance, route adherence)
- IoT-enabled smart bins (fill-level sensors)
- Real-time route optimization software
- Pneumatic collection systems
- Digitalized deposit-return collection equipment
- RFID tags

This section explores these tools and how they address specific waste collection challenges in greater detail.

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### The problem that needs addressing: Inefficient routing

Traditional waste collection routes are often static and do not account for real-time variations in bin fill levels, waste generation patterns, or time lost in traffic congestion. This can lead to unnecessary trips to empty bins, missed collections for overflowing bins, and inefficient use of fuel and labor. These inefficiencies increase operational costs, reduce service reliability, and negatively affect customer satisfaction.

### How route optimization tools help

Specific tools to optimize routes in real time include:

- IoT-enabled smart bins
- Real-time route optimization software
- Vehicle telematics, such as GPS-enabled collection vehicles and diagnostics
- Vehicle telematics and diagnostics to support fuel, driver-behavior, and maintenance monitoring

Real-time data from IoT-enabled smart bins equipped with fill-level sensors, GPS-enabled collection vehicles, and live traffic data can dynamically optimize waste collection routes using real-time route optimization software. The system continuously monitors bin status, vehicle locations, and traffic conditions, recalculating routes to prioritize full bins, avoid congestion, and minimize travel distances. Smart bins transmit status updates to a central dashboard, enabling data-driven scheduling. Dynamic routing reduces fuel consumption and operational costs and minimizes unnecessary trips. It also reduces overflow and littering, enhancing urban hygiene and aesthetics.

Integrating vehicle telematics and diagnostics strengthens this system by providing live data on fuel use, driver behavior, vehicle health, and route adherence. This helps supervisors identify avoidable fuel burn, prevent breakdowns through preventive maintenance, and ensure that vehicles follow the most efficient paths.

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Additional benefits could come by installing integrated waste compactors in smart bins. Often powered by solar energy, these devices compress waste to increase capacity and reduce collection frequency. Compacting bins extend the time between pickups, freeing staff for higher-value tasks, and reducing noise and emissions from frequent collections. Another add-on: IoT sensors, which can detect if the bin has tilted or fallen, measure temperature for fire detection, or analyze the composition of waste.

Note that such options come at an additional cost, which should be considered against the additional benefits these sensors may provide.

### Real-world use case

SAN FRANCISCO, USA: SMART BINS AND DYNAMIC ROUTING



#### Results

80% reduction in bin overflows, 64% drop in illegal dumping, 66% decline in service requests.



#### Takeaway

Real-time data reduces unnecessary trips and improves street cleanliness.<sup>55</sup>

### Route optimization tool requirements

- IoT-enabled smart bins with fill-level sensors
- GPS tracking devices installed on collection vehicles
- Central routing platform with optimization algorithms and bin telemetry integration for monitoring
- Reliable connectivity for real-time data transmission
- Staff training
- Newer vehicles might be needed: Vehicles must have diagnostic interface hardware to function effectively.

### Real-world use case

LAHORE, PAKISTAN: TELEMATICS / IOT-ENABLED OPERATIONAL OPTIMIZATION OF ROUTING AND FLEET MANAGEMENT



#### Results

29% reduction in fuel use, 18% drop in maintenance costs, 32% improvement in route efficiency.



#### Takeaway

Telematics supports preventive maintenance and cost control.<sup>56</sup>

## Investment costs and returns

Retrofitting existing bins for smart bins and connectivity infrastructure can be low cost, however, installation and maintenance costs should be considered. For example, a sensor could cost €150 (about \$175) per waste bin per month, including maintenance costs.<sup>57</sup>

For example, in 2019, the Manchester (England) City Council spent £250,000 (approximately \$333,000) on 51 new solar-powered smart bins, averaging about £5,000 per bin (approximately \$6,650).<sup>58</sup> Compacting bins have higher CAPEX than standard smart bins but deliver greater savings in high-demand areas by reducing collection frequency. Ongoing subscription fees for routing software and data services tend to be additional, though vendors may offer subscription-based models to reduce upfront costs.

Vehicle telematics and diagnostics tools are typically subscription-based and charged per vehicle per month. Costs vary by feature. For instance, in the US, the cost of a subscription could range between \$25 and \$50 per vehicle per month.<sup>59</sup> Integration with other software such as existing maintenance systems or enterprise resource planning (ERP) platforms will come with additional costs.

Savings from reduced downtime, optimized maintenance schedules, and improved fuel efficiency can often offset costs, potentially in less than 12 months. One study suggested that a fleet tracking system could save the average operation between 13 percent and 20 percent on fuel.<sup>60</sup>

There is strong return-on-investment potential in dense urban areas or large fleets where dynamic routing and compaction significantly reduce fuel use, labor hours, and vehicle wear. Payback periods can range between 6 and 18 months, depending on fleet size, waste generation variability, and collection frequency reductions.<sup>59</sup> For smart bins with compaction systems, the strongest returns on investment come in busy locations with high waste volumes, because compaction significantly cuts pickups: two-to-five-times capacity gains, depending on material mix.

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## The problem that needs addressing: Overuse of collection vehicles

Frequent collection vehicle movements through urban areas can lead to traffic congestion, noise, emissions, and safety risks. In dense city environments, curbside bins can also create aesthetic and hygiene challenges, while manual collection remains labor-intensive and costly.

### How pneumatic collection systems help

Underground pneumatic waste collection systems, which require IoT-enabled smart bins, use a network of underground pipes connected to waste inlets located in residential or commercial buildings and public spaces. Waste is deposited into these inlets and transported via high-speed airflow to a central collection station, eliminating the need for traditional curbside pickup. IoT sensors in waste inlets monitor fill levels, enabling real-time alerts and predictive maintenance. Centralized software collects operational data, providing dashboards for performance monitoring and planning. Pneumatic systems can reduce unsorted waste by providing multiple waste inlets for separate fractions and enabling efficient transport dense urban environments.

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## Real-world use case

STOCKHOLM, SWEDEN: DIGITALLY CONTROLLED UNDERGROUND PNEUMATIC COLLECTION SYSTEMS



### Results

90% reduction in collection traffic, 66% decline in unsorted waste; 71% drop in emissions.



### Takeaway

Pneumatic systems deliver major benefits in high-density developments.<sup>62</sup>

## Pneumatic waste system requirements

- Underground pipe network
- Waste inlets installed in buildings and public spaces: Designed for multiple waste streams with integrated sensors for fill-level monitoring.
- Central collection facility equipped with air-handling systems and waste compactors.
- IoT-enabled control units: Requirements include digital control and monitoring software for system operation, predictive maintenance, and data analytics.
- Reliable power supply
- Maintenance protocols

This solution is best suited for high-density urban developments or new city districts where infrastructure and digital systems can be integrated during construction.

## Pneumatic waste collection system investment costs and returns

This solution necessitates very high capital investment for infrastructure development:

- Civil works
- Pipe installation
- Central station construction

Additional costs include IoT sensors, software development, and connectivity.

Costs can range from €2.3 million–€13.6 million (approximately \$2.7 million–\$15.8 million), varying significantly based on size of the system, with €835 (approximately \$973) average investment per inhabitant.<sup>63</sup>

Ongoing costs include energy for pneumatic transport, maintenance of mechanical and digital components, and software updates. For example, the city of Barcelona allocated €2.3 million (approximately \$2.7 million) to replace 221 pneumatic collection boxes.<sup>64</sup>

Long-term benefits include reduced labor costs, lower truck fleet requirements, improved urban quality of life, and enhanced operational efficiency via data-driven planning.

These investments typically come with long payback periods and depend on population density and waste volumes: between 7 and 10 years in new urban development areas and more than 10 years for retrofits in existing urban environments.<sup>65</sup>

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## The problem that needs addressing: Inefficient deposit-return schemes

Traditional deposit return schemes (DRS) rely on manual processes, paper vouchers, or physical redemption points. These processes can be inconvenient for consumers, costly for operators, and challenging for tracking deposits, preventing fraud, and analyzing performance data.

### How digitalized DRS collection equipment helps

Advanced DRS solutions utilize digital technology to streamline operations and enhance user convenience. The core infrastructure includes reverse vending machines (RVMs) equipped with barcode scanners and IoT connectivity to identify containers, process returns, and credit deposits digitally to user accounts or mobile wallets. The machines can integrate with mobile apps or web platforms, allowing consumers to track their refunds, locate nearby RVMs, and access educational content on recycling. Additional digital features include QR codes on containers for fraud prevention, real-time data dashboards for operators, and automated reporting for compliance.

While implementing DRS is primarily a matter of national government policy, municipalities and waste companies can also play a part in DRS financing and operations. City councils can establish new deposit redemption sites, which very often include RVMs, and can sometimes receive grant funding from DRS operators to do so. Waste companies can have operational involvement in both logistics and sorting. They also can help with RVM installation.

### DRS requirements

- RVM network
- Secure digital payment integration: Mobile wallets, bank transfers, or app-based credits
- Mobile app and/or web platform for user interaction: Refund tracking, RVM locator, recycling tips
- Centralized data management system: For transaction logging, fraud detection, and performance analytics

### DRS investment costs and returns on investment

Costs include:

- Initial investment for RVM infrastructure and software development:
  - Small-scale machines suitable for small stores or offices: \$5,000–\$10,000
  - Machines suitable for supermarkets and malls: \$10,000–\$25,000
  - High-capacity machines suitable for large recycling centers: Up to \$50,000<sup>66</sup>
- Ongoing costs for maintenance, connectivity, and payment processing: After initial set-up costs, generally licensing or subscription fees for analytics platforms can range between \$200 and \$500 per month.<sup>67</sup>

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Long-term returns on investment come through reduced litter management costs, improved recycling rates, and potentially through revenue from recovered materials. Digital systems also reduce fraud and administrative overhead.

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## The problem that needs addressing: Opaque waste collection

Traditional waste collection systems lack detailed traceability of individual bins and user-level accountability. This makes it difficult to verify service delivery, monitor participation in recycling programs, and implement fair billing models such as Pay-As-You-Throw (PAYT). Manual identification methods are prone to errors and inefficiencies, limiting the ability of operators to track waste flows accurately and engage citizens in performance-based systems.

### How RFID tags help

RFID tags attached to waste bins, combined with readers installed on collection vehicles, enable full traceability of collections, and user recognition. It also allows for implementing the PAYT model by linking bin IDs to customer accounts. Benefits include improved operational transparency and accurate verification of service delivery. RFID systems support data-driven planning, help identify non-compliant households, allow the quick and seamless resolution of missed bin claims as all collections are registered, and enable incentive-based programs to promote recycling. In contexts where PAYT is implemented, RFID ensures fair billing based on actual service usage, reducing disputes and encouraging waste reduction.

### RFID tag requirements

- Waste bins fitted with RFID tags.
- For PAYT systems: Bins fitted with a lock mechanism that can be unlocked by users to enable user traceability.
- RFID readers: Mounted on collection vehicles and integrated with onboard data systems.
- Central data platform: For logging and analyzing collection events.
- Connectivity for data transfer: Either real-time or batch upload.
- Staff training.

### Real-world use case

SEOUL: RFID-EMBEDDED FOOD WASTE WEIGHT-BASED SYSTEMS



#### Results

10% decline in food waste generated between 2013 and 2019.<sup>68</sup>



#### Takeaway

Simplified payment systems and tracking can help drive behavior change.

## RFID costs and returns on investment

The costs include initial investment for RFID tags and vehicle-mounted readers, plus software platform costs.

- Per-unit tag costs are relatively low, from \$3 to more than \$20 depending on durability and features: Total expense will depend on fleet size and number of bins.<sup>69</sup>
- Subscription-based data platforms can reduce upfront IT costs: Licensing or subscription fees for analytics platforms can range between \$200 and \$500 per month.
- Ensuring compatibility with existing billing, fleet management and other IT systems can increase implementation costs: Integration costs can push costs into the \$20,000–\$200,000 range depending on complexity.<sup>70</sup>
- Lock mechanisms for bins, needed for PAYT systems, will further increase capital costs.

There is strong potential for returns on investment when linked to PAYT or compliance programs, as accurate data improves billing fairness and reduces revenue leakage.

Operational benefits include reduced manual record-keeping and faster verification of missed collections, as well as reliable data for planning purposes, which can be used to improve round design and efficiency. Operators can plan for phased deployment starting with high-priority zones, such as undertaking a PAYT pilot in a specific area.



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## *Waste treatment infrastructure tools*

Waste treatment tools support operations, data collection, and monitoring in recycling plants, composting units, and waste-to-energy facilities.

### Foundational solutions

Foundational solutions include low-complexity tools that replace manual records, improve waste data, and increase the reliability of customer billing, such as:

- Digital weighbridges with recording platforms: To provide accurate, auditable tonnage for billing/planning
- Digital reporting tools

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### **The problem that needs addressing: Lack of consistent, high-quality, and timely data**

Many waste management facilities lack consistent, reliable data on incoming and outgoing waste tonnages. Paper-based logs or ad-hoc spreadsheets are time-consuming, error-prone, and difficult to consolidate, making it hard to reconcile customer charges, track operating performance, or demonstrate compliance.

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## How digital recording platforms help

Digital recording platforms enable weighbridge operators to capture key information at each transaction, including:

- Date/time
- Vehicle license plate
- Customer/account
- Gross/tare/net weights
- Material type

Data can be aggregated and analyzed at agreed intervals (daily/weekly/monthly) to provide a clear picture of tonnages entering and leaving the facility. By digitizing weighbridge operations, facilities gain accurate and timely data that supports load-based billing, reduces disputes, and improves revenue assurance.

Digitalization also enables better operational planning by identifying peak traffic periods and average load sizes, helping optimize staffing and equipment use. Digital records simplify compliance reporting, enhance transparency, and provide a foundation for future upgrades such as automated invoicing.

### Real-world use case

#### BOGOR REGENCY, INDONESIA: DIGITAL WEIGHBRIDGE DATA AND MATERIAL FLOW ANALYSIS



##### Results

Improved visibility of waste flows and landfill capacity, evidence-based planning and CO<sub>2</sub> reduction scenarios.



##### Takeaway

Digital weighbridge data enables accurate billing and strategic planning.<sup>71</sup>

## Requirements

- Weighbridge hardware (existing or new): Capable of measuring gross/tare/net weights.
- Basic IT equipment and internet connectivity: Or local network with periodic sync.
- For more advanced systems: Cameras with license plate recognition to minimize manual data recording of vehicle movements, although these come at an additional capital cost.
- Staff training for weighbridge operators and supervisors.

## Digital platform investment costs and returns on investment

Digital platforms can be subscription-based, per site or per transaction, or a one-time license. For instance, in India, a weighbridge system license for one location could cost 25,000 Indian rupees (approximately \$260), or 45,000 Indian rupees (approximately \$470) a year for multiple locations.<sup>72</sup>

Optional peripherals add capability and cost. These peripherals include ticket printers, barcode/RFID readers, and automatic number plate recognition (ANPR) cameras. A complete turnkey weighbridge system with an ANPR camera solution could cost tens of thousands of dollars.

These investments typically yield swift, strong returns, due to improved billing accuracy, reduced administrative effort, and fewer customer disputes. Additional savings come from optimized staffing and better queue management.

### The problem that needs addressing: Compliance gaps

Traditional environmental reporting, which often relies on paper forms or manual data entry, can be time-consuming and error-prone, leading to compliance gaps and fines, delayed reporting, and challenges for regulators in tracking progress toward environmental standards.

### How digital reporting tools help

Digital reporting solutions use web-based forms or mobile applications so operators can collate and submit compliance data electronically. These tools allow real-time or scheduled reporting on critical environmental metrics, reducing administrative burdens and improving data accuracy. Reports can be automatically stored and shared with regulators, supporting oversight and ensuring timely compliance. The benefits include enhanced transparency, streamlined workflows, error minimization, improved regulatory monitoring, and better alignment with environmentally sound management standards. There is potential to expand the system over time to cover additional compliance parameters or integrate with other digital tools.

### Requirements

- Internet connectivity at facilities for data submission.
- Basic smartphones or computers for operators to access web forms or mobile apps.
- Secure digital platform for data entry, storage, and reporting: Typically provided by the vendor.
- Staff training.

#### Real-world use case

BOGOTÁ, COLOMBIA: AUTOMATED ENVIRONMENTAL MONITORING AT DOÑA JUANA



#### Results

Long-running landfill gas (LFG) monitoring and reporting under the Kyoto Protocol's Clean Development Mechanism (CDM), geotechnical studies strengthened instrumented stability/monitoring practices after historic failures.



#### Takeaway

Digital reporting and monitoring improve regulatory compliance and operational risk management at large landfills.<sup>73</sup>

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## Digital platform investment costs and returns

Digital reporting platforms are typically subscription-based or included as part of broader compliance software packages; costs are generally modest compared to hardware-intensive solutions. Capital costs include IT equipment for staff (such as tablets and PCs). Consideration should be given to the implementation and customization costs which may be charged on top of the subscription costs and can be substantial.

High returns on investment come from reduced administrative time, improved compliance, and avoidance of penalties for late or inaccurate reporting.

## Enhanced solutions

Advanced tools that automate monitoring, improve quality, and reduce downtime include:

- Digital plant operating systems, such as supervisory control and data acquisition systems (SCADA)
  - IoT sensors: Including real-time process control, alarms, and trend analysis.
  - Sensor-based digital sorting: Such as optical/NIR/X-ray for consistent, higher-speed separation.
  - AI-enabled sorting systems: Such as computer vision/robotics for higher purity and throughput.
  - Digital twins: To simulate operations, predict failures, and optimize energy and capacity.

This section explores these tools and how they address specific waste management challenges in greater detail.

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## The problem that needs addressing: Manual inspections

Traditional manual inspections of environmental parameters, such as gas and water emissions, are labor-intensive, prone to delays, and can fail to detect anomalies promptly. This increases the risk of environmental hazards, non-compliance and inefficient plant operations.

## How digital plant operating systems help

Digitalized plant operating systems, such as SCADA, combined with IoT sensors, provide real-time monitoring and control of facility operations. IoT sensors measure critical parameters—gas composition, temperature, flowrate, fill-level—and transmit data to a centralized SCADA platform. Operators can visualize system performance, receive automated alerts when readings exceed predefined thresholds, and remotely adjust equipment settings. This integration significantly reduces reliance on manual inspections, strengthens process control, improves environmental safety, and enhances compliance with regulatory standards.

Such systems can expand to monitor additional parameters or facilities as needed. It is important to assess vendor capability for multi-site integration prior to expansion, however.

### Real-world use case

#### GERMANY: IOT-ENABLED PREDICTIVE MAINTENANCE IN RECYCLING PLANTS



##### Results

Unplanned downtime avoided; maintenance savings exceeded system costs in documented industry cases; moderate service fees quickly recovered.



##### Takeaway

Real-time sensing + SCADA enable predictive maintenance with fast payback.<sup>74</sup>

### Requirements

- IoT sensors capable of measuring relevant parameters.
- Connectivity modules for real-time data transmission.
- Centralized SCADA platform with visualization.
- Alerting and control capabilities.
- Secure servers or cloud infrastructure for data storage and processing.
- Staff training.

### SCADA investment costs and returns

Costs include initial investment for IoT hardware, SCADA software licensing, and integration, and can vary widely depending on system size, complexity and features. The initial purchase price for a small to medium-sized SCADA turnkey solution could range between \$10,000 and \$100,000.<sup>75</sup> Ongoing costs include software updates, hardware replacements, and system checks, with costs ranging from a few thousand dollars to tens of thousands depending on system complexity. Additional costs may apply for tech support (\$50–\$150 per hour), subscription fees for data management, and cybersecurity measures. There is strong potential for returns on investment through reduced labor costs for manual inspections, improved compliance, optimized energy use, and avoidance of environmental penalties. The payback period depends on facility size and regulatory requirements.

### The problem that needs addressing: Manual waste sorting

Manual waste sorting is labor-intensive, costly, and inconsistent. Traditional mechanical systems can separate materials by size or weight but struggle with complex, mixed waste streams. As waste volumes grow and recycling targets tighten, traditional sorting methods struggle to keep pace with efficiency and quality requirements.

### How digitalized sorting technologies help

Digitalized sorting technologies enhance traditional mechanical processes by integrating sensor-based systems and, at the cutting edge, AI-driven solutions.

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Sensor-based systems use optical sorters, near-infrared (NIR) spectroscopy, X-ray, and established algorithms to identify materials by physical or chemical properties. These systems enable high-speed, automated separation of materials with consistent accuracy. They can expand easily, with additional sorting lines or sensors.

AI-driven systems go further by using machine learning and computer vision to identify items based on shape, color, and brand markings, even in highly contaminated streams. Robotic arms guided by AI can pick individual items with precision, adapting to changing waste compositions over time.

Benefits include higher recyclable purity, greater throughput, reduced labor dependency, and improved adaptability. AI systems also generate valuable operational data for predictive maintenance and continuous improvement. AI models can adapt to new materials without major hardware changes, making them ideal for evolving waste compositions.

### Real-world use case

#### SWITZERLAND: SITE ZERO ADVANCED SORTING FACILITY



#### Results

Up to 95% recovery; more than 90% purity across 12 fractions using NIR + AI.



#### Takeaway

Sensor + AI sorting delivers high purity at scale for complex streams.<sup>76</sup>

### Requirements

Sensor-based digital sorting systems:

- Mechanical sorting infrastructure: Including conveyors, screens, air classifiers, magnets, and eddy current separators.
- Optical sorting units with NIR sensors for polymer identification.
- X-ray or metal detection sensors for material differentiation.
- Reliable power supply and industrial connectivity for data exchange.
- Skilled staff for system operation and routine calibration.

AI-driven sorting systems:

- High-resolution cameras and computer vision hardware.
- AI software platform with machine learning algorithms for material recognition.
- Robotic arms or automated pickers integrated with AI control systems.
- GPU-enabled servers or cloud infrastructure for real-time image processing.
- Skilled staff for AI model training, calibration and troubleshooting.

### Digital sorting system investment costs and returns

Costs for sensor-based digital sorting systems involve upfront investment for optical and sensor units and ongoing costs for calibration and maintenance. Returns on investment are seen in payback through improved recovery rates, lower labor

costs, and reduced contamination. Returns are strongest for large facilities with predictable waste streams. Costs for AI-driven sorting systems involve initial investment in vision systems, robotics, and AI software and ongoing costs for updates and hardware servicing. Payback depends on material resale value and throughput gains. Returns are highest in facilities handling complex or mixed waste streams where traditional sensors underperform.

## The problem that needs addressing: Too much downtime

Waste management facilities are complex systems with multiple interdependent processes. Traditional monitoring and planning methods often rely on static models or manual data interpretation, limiting the ability to predict operational issues, optimize performance, and plan for future scenarios.

### How digital twins can help

A digital twin is a virtual replica of a physical facility that integrates real-time operational data with simulation models. Sensors and IoT devices feed live data into the digital twin, enabling operators to visualize processes, monitor equipment health, predict failures, optimize energy and capacity, and simulate different operational scenarios.

Advanced digital twins can incorporate predictive analytics and AI to forecast equipment failures, optimize energy use, and evaluate the impact of process changes before implementation.

Benefits include enhanced operational efficiency, predictive maintenance to reduce downtime, and data-driven decision-making for capacity planning and resource allocation. Digital twins also support training and scenario testing, allowing operators to model emergency responses or evaluate the effect of new technologies without disrupting live operations. They also can expand over time to cover additional processes or multiple facilities as systems evolve.

### Real-world use case

#### COLOMBIA: DIGITAL TWIN ASSISTED COMPOSTING OPERATIONS



#### Results

Efficiency gains of about 10%.



#### Takeaway

Digital twins support predictive optimization and scenario testing before live changes.<sup>77</sup>

### Requirements

- IoT sensors and data acquisition systems for real-time monitoring of key parameters: Such as flow rates, temperatures, and emissions.
- High-performance computing infrastructure or cloud services for data processing and visualization.
- Integration with existing SCADA or plant control systems for seamless data flow.
- Skilled staff for system configuration, data interpretation, and scenario modeling.

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### **Digital twin investment costs and returns on investment**

Costs include investments in software, integration, and IoT infrastructure. Medium-scale digital twin deployments, not specific to waste management facilities, can cost between \$100,000 and \$500,000, covering multiple assets or departments, including moderate integration with existing IT infrastructure and more advanced analytics. More complex systems could increase costs.<sup>78</sup> Ongoing costs include data storage, software updates, and maintenance.

Digital twin investments offer strong potential for positive returns through reduced downtime, optimized energy use, and improved planning. As facility complexity and scale increase, the time to payback decreases.



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## *Digital trading platforms and marketplaces*

Digital recycling marketplaces are transforming waste management by connecting citizens, recyclers, and buyers of secondary materials. These marketplaces are reducing transaction costs, improving pricing, and earning better financial outcomes. They include mobile apps, online marketplaces, and integrated payment systems to enable transparent transactions and promote circular-economy principles.

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### **The problem that needs addressing: Sourcing feedstock, finding buyers**

Waste management companies often face challenges in sourcing feedstock and finding buyers for recovered materials. Traditional procurement and sales channels rely on fragmented networks, manual negotiations, and limited market visibility, which can lead to offtake uncertainty. This issue can represent a disincentive to invest in the recycling business. It also results in inconsistent supply, missed revenue opportunities, and higher transaction costs.

### **How a foundational digital marketplace solution helps**

Digital marketplaces are a low-complexity solution that can help find and connect feedstock suppliers and buyers for recovered materials. They offer an online platform where waste facilities can procure feedstock—also known as recyclables—and sell outputs such as secondary raw materials. Platforms typically include features like real-time listings, price benchmarking, quality certifications, and secure payment systems. Advanced marketplaces also might feature integrated logistics support, traceability tools, and compliance verification to ensure transactions meet regulatory standards.

Benefits include greater market transparency, access to a wider network of suppliers and buyers, and reduced transaction time and costs.

Marketplaces have scale-up potential as well. They can expand to include multiple material streams and integrate with logistics providers for end-to-end service, subject to digital marketplace platform functionality.

### Real-world use case

#### CHENGDU & SUZHOU, CHINA: INTEGRATED DIGITAL RECYCLABLE TRADING



##### Results

Up to 98% sorting accuracy; 5,778 tonnes of plastics diverted in 2024; scaled to 31,500 smart recycling machines across multiple cities.<sup>79</sup>



##### Takeaway

Marketplaces + logistics integration de-risk offtake and make revenues more predictable as recycling volumes grow.

### Requirements

- Reliable internet connectivity for real-time transactions
- Digital payment systems
- Compliance verification tools
- Staff training

### Digital marketplace investment costs and returns

Typically, digital marketplaces are either subscription-based, with costs at around \$500 per year, or use transaction-fee models, with costs varying by platform features and transaction volume.

Marketplaces can unlock positive returns for all participants, through improved sales of recovered materials, reduced procurement costs, and better price discovery.

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# Endnotes

- 1 Examples reflect results in particular cities; actual outcomes depend on local context including governance, operations, and citizen participation.
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