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From Waste Diagnosis to Transition Design: A Multi-scale Framework for Organics-First Reform in Cusco, Peru

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A B S T R A C T

Municipal solid waste systems cannot be judged by collection alone, because high service reach may coexist with weak downstream control and limited recovery. This study develops a multi-scale prioritization framework for organics-first reform in Cusco, Peru, under disposal constraint. The analysis integrates 2019–2024 official waste statistics, district and generator characterization records, tourism data, oversight documents, and field evidence from 2024 stakeholder meetings and interviews. Results show rising waste pressure, stable organics dominance, and a sharp downstream bottleneck. Total municipal solid waste increased by about 22% between 2019 and 2024, while organics remained about 58–60% of the waste stream. In 2023, 94.41% of waste still went to non-sanitary dumping, whereas composting and recovery together remained below 6%. District and generator evidence further shows that average-based planning masks operationally important differences in organics yield, recyclable quality, contamination risk, and service-design needs. The framework therefore prioritizes minimum disposal control first, organics capture at controllable nodes second, and differentiated scale-up with continuity, monitoring, and accountability third. The study contributes a practical bridge from waste diagnosis to transition design for disposal-constrained, organics-dominant cities.

INTRODUCTION

Municipal solid waste management should be judged by what happens after collection as well as at the curb. Recent reviews show that waste-hierarchy and circular-economy goals weaken when treatment, disposal, and recovery remain poor (Awino & Apitz, 2024; Oo *et al*., 2024). Cities can therefore appear efficient at the household interface while still generating high downstream environmental risk.

This challenge is acute in many developing urban systems, where rising waste volumes coexist with weak treatment infrastructure, financial limits, and uneven monitoring (Zhang *et al*., 2024). Organics often remain the dominant fraction, which creates major diversion potential but also raises contamination and quality-control demands for biological treatment (Okori *et al*., 2024).

The problem is also institutional. Municipal outcomes depend on regulatory quality, accountability, and government effectiveness, not only on collection assets or formal plans (Sasahara *et al*., 2024). Collaborative governance also matters where service chains depend on shared infrastructure and multiple actors (Abdulai *et al*., 2024).

Latin America is therefore a relevant setting. Recent regional reviews identify policy momentum, but also persistent barriers in infrastructure, finance, market development, and public participation (Gallego-Schmid *et al*., 2024). Benchmark frameworks remain valuable for diagnosis, comparison, and prioritization, as shown by Wasteaware's wider application and the recent Cali study (Giraldo-Almario *et al*., 2024; Wilson *et al*., 2015).

However, diagnosis alone is not enough for disposal-constrained cities. A city may know its weak points and still lack a defensible reform order. What remains less developed in the literature is a practical bridge from waste diagnosis to transition design under real service constraints.

Cusco is a strong case for this question. Official evidence indicates rising waste pressure, persistent organics dominance, strong tourism-linked service demand, and continued downstream weakness around Haquire (DGGRS, 2025; MINAM, 2025; MINCETUR, 2025; OEFA, 2023). At the same time, province-level evidence reveals system pressure, while MPC data reveal operationally distinct generators and actionable intervention nodes (MPC, 2020, 2024a, 2024b).

Accordingly, this study develops a multi-scale prioritization framework for organics-first reform in Cusco. It asks where the binding bottleneck lies. It then asks which nodes offer the strongest early leverage and what reform order is feasible under current constraints. The paper first links province-level diagnosis with MPC-level targeting. It then converts evidence into screened packages, grounds sequence in field-verified feasibility, and distills conditional lessons for similar cities.

STUDY CONTEXT AND ANALYTICAL FRAMING

Cusco system context and disposal constraint

This study adopts a nested multi-scale boundary. Cusco Province is the primary unit for system diagnosis. It captures waste growth, district heterogeneity, and shared downstream dependence. Within that provincial frame, the Provincial Municipality of Cusco (MPC) is treated as the focal operational subsystem for near-term transition design. MPC provides the most detailed recent evidence on generators, programmes, and actionable intervention nodes (MPC, 2020, 2024a, 2024b).

This boundary reflects service reality rather than a narrow cartographic line. Waste generation and front-end collection occur across districts, but downstream control depends on linked facilities, institutions, and routes. The same residual chain also shapes near-term circular options, because diversion gains remain limited while final disposal remains weak (MPC, 2020; OEFA, 2023; Project field-visit records April–May, 2024).

The boundary choice also prevents an analytical mismatch. Province-level evidence is needed to diagnose shared pressure and disposal dependence. MPC-level evidence is needed to identify realistic early nodes for reform. The study therefore combines province-level diagnosis with MPC-level intervention design, rather than treating them as separate cases (DGGRS, 2025; MINAM, 2025; MPC, 2024a, 2024b).

This framing supports a coherent multi-scale structure. Figure 2 reads the system-level pressure and bottleneck. Figure 3 identifies differentiated opportunity nodes. Figure 4 then translates that diagnosis into a phased transition pathway.

Organics-first transition as the analytical lens

This study uses an organics-first lens because organics remain the largest fraction of Cusco's municipal waste stream. In disposal-constrained systems, the largest fraction usually offers the strongest near-term leverage on residual pressure and site life (Awino & Apitz, 2024; MPC, 2024a).

However, the analysis does not treat organics as a stand-alone technical fix. Circular transition in weak-control systems depends on sequencing, service reliability, and downstream conditions. Where disposal remains poorly controlled, diversion cannot deliver its full environmental value (OEFA, 2023; Oo *et al.*, 2024).

The organics-first lens therefore rests on four propositions. First, early transition should target the largest and most policy-relevant flow. Second, early action should begin in controllable nodes, not across the whole city at once. Third, minimum disposal control must precede broad circular expansion. Fourth, participation will not last where schedules are unreliable or separated waste is later remixed (Abdulai *et al.*, 2024; Project field-visit records April–May, 2024; Project stakeholder interviews August, 2024).

This lens fits Cusco's observed conditions. The system remains disposal-dependent, yet organics still offer the clearest early diversion opportunity. At the same time, programme reach, route reliability, storage conditions, and treatment continuity remain uneven across nodes (MPC, 2024b; Project field-visit records April–May, 2024; Project stakeholder interviews August, 2024).

Evidence-to-transition design framework

Figure 1 summarizes the evidence-to-transition design framework. The framework moves through three linked steps. It first diagnoses system pressure and the main downstream bottleneck. It then reveals where average-based planning fails. Finally, it converts that diagnosis into screened nodes and sequenced intervention packages.

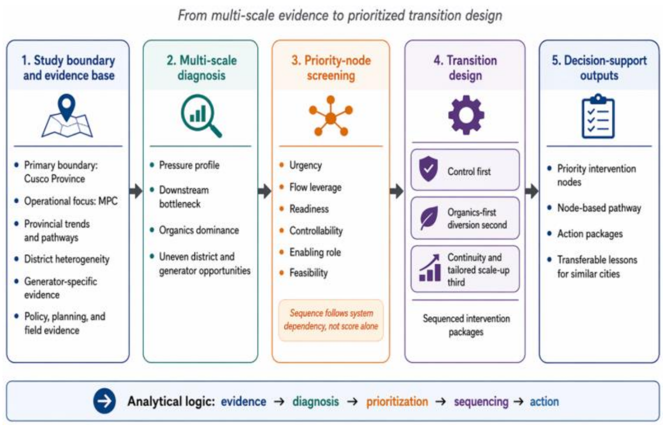

Figure 1: Evidence-to-transition design logic for organics-first reform in Cusco

The framework is diagnostic and decision-oriented. It does not predict a single future pathway. Instead, it uses available evidence to identify which actions should come first under current constraints. This design is appropriate where waste evidence is uneven across scales but still strong enough for practical prioritization (DGGRS, 2025; MINAM, 2025; MPC, 2024b, 2024a).

The first block uses official time-series and oversight evidence to identify pressure and constraint. The second block uses district and generator heterogeneity to reveal where differentiated action is possible. The third block uses field and operational evidence to test whether candidate nodes are workable under current service conditions (OEFA, 2023; Project field-visit records April–May, 2024; Project stakeholder interviews August, 2024).

The framework therefore links evidence, feasibility, and reform order. It asks not only what the waste system looks like, but which nodes are ready, controllable, and system-enabling. That link is the study's core contribution, because it turns diagnosis into phased transition design for a disposal-constrained, organics-dominant city (Awino & Apitz, 2024; Ospina-Mateus *et al.*, 2023).

DATA AND METHODS

This study used a diagnostic and decision-support design. It did not estimate one optimal future pathway. Instead, it linked multi-scale waste evidence to a feasible transition sequence under current disposal constraints.

Data streams and evidence base

The evidence base combined official statistics, municipal planning records, operational records, oversight documents, and structured field materials for 2019–2024. Province-level data were used to diagnose system pressure and downstream dependence. MPC-level data were used to identify actionable intervention nodes, because MPC provided the richest recent generator evidence.

Core administrative evidence came from SIGERSOL, PIGARS-Cusco, MPC programme and operational records, and oversight documents from OEFA. These sources defined waste growth, composition, pathway dependence, institutional setting, and disposal risk (DGGRS, 2025; MINAM, 2025; MPC, 2020, 2024a, 2024b; OEFA, 2023). District composition records were used to identify spatial heterogeneity. Generator-specific characterization records were used to identify node-specific material signatures. Tourism overnight-stay series were used to interpret service-sector pressure in a tourism-intensive system (MINCETUR, 2025).

Field materials had two roles. First, the April 2024 meetings and site visits clarified programme scale, composting practice, disposal conditions, and implementation bottlenecks. Second, the August 2024 interviews tested user willingness, schedule fit, storage limits, and service credibility. These materials were used for triangulation and feasibility checking. They were not used to replace official quantitative values (Project field-visit records April–May, 2024; Project stakeholder interviews August, 2024).

Table 1 summarizes the evidence streams used to diagnose system pressure, reveal district and generator heterogeneity, identify priority nodes, and test the operational realism of phased reform in Cusco. Together, these streams link formal system evidence with operational and user-side implementation realities.

Table 1: Data streams and analytical role in the transition framework

Evidence stream	Key examples	Years	Analytical use	Confidence
National policy and regulatory framework	Legislative Decree No. 1278; DS No. 014-2017-MINAM; MINAM technical guides; related municipal planning requirements	2017–2024	Defines the policy and regulatory baseline for interpreting Cusco's delivery gap	High
Municipal planning and diagnostic records	PIGARS-Cusco; PEI/POI-linked materials; municipal service and programme documents	2019–2024	Defines the local boundary, institutional setting, planned assets, and programme structure	High
National MSW administrative reporting	SIGERSOL dynamic reporting for MSW generation, per-capita generation, composition, and pathway data	2019–2024	Supports diagnosis of waste growth, organics dominance, and pathway dependence	High
District-level waste characterization	Official 2024 district composition records harmonized from the national characterization system	2024	Reveals spatial heterogeneity in diversion potential and contamination burden	High
Generator-specific waste characterization	MPC 2024 generator profiles for households, markets, restaurants, hotels, institutions, commercial sources, and public-space streams	2024	Identifies generator-specific opportunity nodes for organics capture, cleaner recycling, and tailored service design	High
Tourism pressure data	MINCETUR lodging-based overnight-stay series, aggregated to annual totals	2019–2024	Helps interpret transient service pressure in a tourism-intensive system	High
Oversight and enforcement records	CGR and OEFA records, including site-management and environmental-control findings for Haquire	2022–2024	Verifies downstream-control weakness, monitoring gaps, and environmental risk	High
Municipal operational and finance evidence	Arbitrios-linked information, programme budgets, procurement traces, route or equipment information where available	2023–2024	Clarifies implementation capacity, continuity constraints, and cost-recovery conditions	Medium
April 2024 stakeholder meetings and field visits	Technical meetings with MPC, NGO Guamán Poma, Recíclame, Haquire visit, composting-plant visits, project planning discussions	2024	Triangulates programme scale, disposal conditions, composting practice, and operational bottlenecks	Medium
August 2024 semi-structured interviews	Residents, restaurants, hotels, and neighbourhood leaders	2024	Tests reliability, willingness, schedule fit, and storage constraints at user level	Medium

Note: Official administrative, planning, and oversight records form the core evidence base. Field materials from April and August 2024 are used mainly for triangulation, implementation checking, and interpretation of service reliability, participation conditions, and delivery bottlenecks.

Data harmonization and analytical use

The analysis used a nested scale. Province-level series supported the pressure profile in Figure 2. District and generator evidence supported the opportunity logic in Figure 3. The screened-node and package design then drew on both levels and was summarized in Table 2, Table 3, and Figure 4.

Data harmonization followed four rules. Official administrative or oversight values were preferred where available. Units were aligned before comparison. Spatial data were matched to the closest functional service geography. Field evidence was used to test plausibility, not to create substitute totals (DGGRS, 2025; MINAM, 2025; MPC, 2024b; OEFA, 2023).

Composition evidence also required harmonization. Province-level time-series used the official reporting structure available through SIGERSOL. District and generator records were then read through a common cross-comparison lens. This allowed early nodes to be compared on material yield, contamination risk, and service-design implications. In this way, average-based readings were replaced by differentiated node selection.

Each evidence stream served a distinct analytical role. Time-series and pathway data identified pressure and the main downstream bottleneck. District and generator data identified where intervention could start. Operational and field evidence then tested whether those candidate nodes were ready, controllable, and credible under current service conditions. This logic links Section 3 directly to Figure 2, Figure 3, and the transition packages in Table 3.

Priority-node screening criteria

Candidate nodes were screened with six criteria: urgency, flow leverage, readiness, controllability, enabling role, and feasibility. Table 2 reports the resulting matrix. Urgency captured immediate environmental or service risk. Flow leverage captured the likely effect on residual disposal pressure. Readiness captured whether a node already had some operational, institutional, or programme base.

Controllability captured whether separation, storage, timing, and material quality could be managed with reasonable discipline. Enabling role captured whether action at that node would unlock later reforms. Feasibility captured whether near-term action was plausible under current capacity, evidence, and governance conditions.

Each criterion was scored on a simple three-point scale. A score of 3 indicated a strong condition. A score of 2 indicated a moderate condition. A score of 1 indicated a weaker condition. Total scores helped distinguish stronger and weaker candidates, but they did not determine sequence alone. Final ordering followed system dependency.

This rule is important in the Cusco case. Some circular nodes scored highly on leverage and readiness. However, weak residual disposal still constrained the whole system. For that reason, nodes that reduced immediate environmental risk or enabled later reform were placed earlier when scores were close. This screening rule explains why residual disposal control entered before wider circular expansion.

Sequencing logic and transition-package design

The screened nodes were then translated into intervention packages. Table 3 presents those packages, and Figure 4 visualizes the phase logic. This step was necessary because isolated measures would not resolve Cusco's transition problem. The system requires linked actions across disposal control, node selection, and continuity.

Three sequencing rules were applied. First, minimum disposal control had to come before broad circular expansion. Second, early organics capture had to begin in controllable nodes, not through diffuse citywide rollout. Third, continuity mechanisms had to protect early gains before larger expansion. These rules came directly from the combined evidence structure used in this study.

The first package therefore focused on minimum disposal control and data reliability at Haquire. The second package focused on organics-first diversion in markets, restaurants, hotels, and selected neighbourhood pilots. The third package focused on differentiated scale-up, monitoring, finance, and accountability. Together, these packages convert diagnosis into a phased transition pathway rather than a generic action list.

The resulting pathway is designed for decision support, but it is not fully prescriptive. It identifies reform order, operational emphasis, and enabling conditions. It does not replace engineering design, procurement planning, or detailed financial appraisal. Those later steps should follow the sequence identified here.

Transferability logic for similar cities

Transferability was treated as conditional. The Cusco framework is not proposed as a universal template. It is most relevant to cities with organics-dominant waste streams, weak downstream control, heterogeneous generators, and fragmented governance across shared assets.

The transferability test was mechanism-based rather than score-based. The question was not whether another city matched Cusco numerically. The question was whether similar structural conditions would produce similar sequencing needs. These conditions are revisited later, where the Cusco lessons are translated into conditional transferability claims.

This approach keeps the framework cautious and usable. It allows analytical transfer without assuming identical institutions, scales, or treatment options. The main transferable lesson is direct. Cities should not begin circular transition through undifferentiated expansion. They should begin from system diagnosis, then move through differentiated node selection, minimum disposal control, and only later broader scale-up under stronger continuity and accountability conditions.

RESULTS

This section moves from system diagnosis to transition prioritization. It first identifies the main pressure profile and bottleneck. It then shows why average-based planning fails. Finally, it presents the screened nodes and the sequenced pathway that emerged from the evidence.

Pressure profile and downstream bottleneck

Cusco's pressure profile combines rising waste, stable organics dominance, tourism-linked service pressure, and a sharp downstream control deficit. Between 2019 and 2024, total municipal solid waste increased from 124,937 to 152,823 t/year, or by about 22%. Over the same period, municipal waste generation rose from 0.71 to 0.80 kg/cap/day. Organics remained the dominant fraction throughout, at about 58–60% of total waste, showing that growth did not alter the main material profile (MINAM, 2025; MPC, 2024a).

Tourism pressure also recovered strongly by 2024. Annual overnight stays in lodging establishments reached 3.55 million person-nights, slightly above the 2019 level. This rebound coincided with the sharpest late-period increase in waste generation and strengthens the interpretation that non-household and service-sector pressures intensified toward the end of the study period (MINAM, 2025; MINCETUR, 2025).

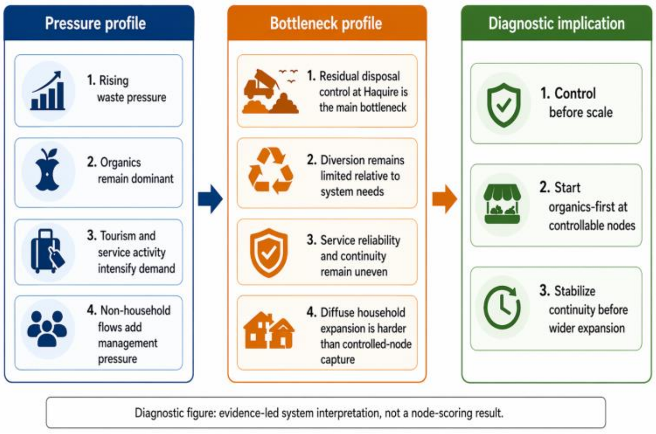

Figure 2: Pressure–bottleneck profile of the Cusco system

Figure 2 synthesizes these pressures with the main system bottleneck. The main result is that rising waste pressure coincided with an overwhelmingly disposal-dependent and environmentally weak downstream pathway. In 2023, Cusco Province still sent 94.41% of municipal waste to non-sanitary dumping, while only 4.46% went to composting and 1.13% to recovery and recycling. The sanitary landfill share remained zero. By contrast, Peru's national profile was led by sanitary landfill at 61.05%, followed by non-sanitary dumping at 36.88%, biological treatment at 1.26%, and recovery and recycling at 0.85% (DGGRS, 2025; MINAM, 2025; OEFA, 2023).

This contrast identifies downstream control, rather than waste generation alone, as the binding system constraint. It also explains why Cusco cannot begin transition from generic circular expansion. The organics opportunity is large, but it remains shaped by a disposal chain that still dominates final outcomes.

Why average-based planning fails in Cusco

Province-wide averages are useful for diagnosis, but they are too coarse for transition design. Figure 3 shows that district and generator evidence reveal materially different entry points for reform. These differences are large enough to change collection logic, contamination risk, and likely diversion performance.

At district level, food waste remained dominant everywhere, but its share varied strongly. It ranged from about 42% in Poroy and San Sebastián to 58% in Cusco District and San Jerónimo. Dry recyclable fractions also varied substantially. Plastics ranged from 9.53% to 17.21%, glass from 1.85% to 7.11%, and disposable diapers from 4.84% to 9.67% across districts. These differences imply unequal diversion potential and unequal contamination burdens across the province (DGGRS, 2025; MINAM, 2025; MPC, 2024a).

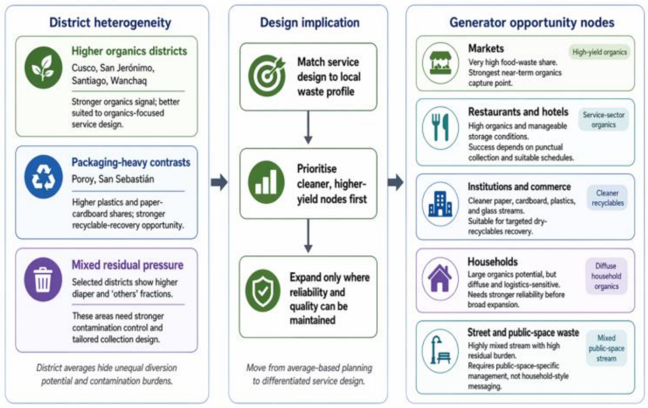

Figure 3: District–generator opportunity matrix for phased transition in Cusco

Generator evidence sharpens this pattern further. Markets and restaurants were strongly food-dominant, at 83.71% and 73.78%, respectively. Hotels and households were also organics-rich, at 53.96% and 60.35%. By contrast, public and private institutions showed stronger dry-recyclable signatures, especially paper and cardboard at 37.10% and plastics at 23.89%. Educational institutions also showed substantial paper and cardboard at 26.54%. Street and public-area waste was different again. It contained only 2.19% food waste and was dominated by mixed "others" at 56.26% (MPC, 2024b).

These signatures show why early reform cannot begin from a uniform citywide campaign. Markets emerge as the strongest high-yield organics node. Restaurants and hotels form a second operationally attractive group, but they depend more on schedule fit and storage conditions. Institutional and commercial streams are better suited to cleaner recyclable capture. Public-space waste and difficult fractions require a different service logic from both organics and dry recyclables. Figure 3 therefore links heterogeneity with the need for differentiated node selection.

Priority intervention nodes for organics-first reform

Table 2 converts the diagnostic evidence into a priority-node screening result. The matrix should be interpreted as a transition filter rather than a mechanical ranking tool. It is a transition filter that combines material opportunity with system dependency, controllability, and feasibility.

Table 2: Priority-node screening matrix for sequenced transition design in Cusco

Priority node	Why it matters	Urgency	Flow leverage	Readiness	Controllability	Enabling role	Feasibility	Total	Tier	Phase
Residual disposal control	• Main environmental bottleneck; • Weak downstream control undermines all later diversion gains	3	3	2	2	3	2	15	A	Phase 1
Market organics	• Highest-yield and most controllable	2	3	3	3	2	3	16	A	Phase 2

Priority node	Why it matters	Urgency	Flow leverage	Readiness	Controllability	Enabling role	Feasibility	Total	Tier	Phase
capture	organics stream; • Can reduce disposal pressure quickly									
Restaurant and hotel organics	• Strong service-sector organics potential where storage, training, and schedule-based collection are more manageable	2	2	3	2	2	2	13	B	Phase 2
Institutional and commercial recyclables	• Cleaner dry recyclables can be captured more reliably than mixed household streams	1	2	2	3	1	2	11	B	Phase 3
Neighbourhood organics pilots	• Important for later scale-up, but diffuse household logistics remain harder and more fragile	2	2	2	1	1	1	9	C	Phase 3
Public-space and difficult fractions	• Needed for cleaner streets and lower contamination, but not an early circular-transition entry point	2	1	1	2	1	2	9	C	Phase 4
Continuity, accountability, and monitoring backbone	• Needed to prevent pilot collapse and convert plans into routine delivery	3	2	2	2	3	2	14	A/B	Cross-cutting; Phase 5 consolidation

Source: This study, based on evidence streams listed in Table 1
Scoring note: 3 = high; 2 = medium; 1 = lower.

Screening rule: Total score guides prioritization, but final sequence follows system dependency. When totals are close, nodes that reduce immediate environmental risk and unlock later reform are placed earlier.

Three findings stand out. First, market organics capture received the highest total score, at 16. Residual disposal control followed closely, at 15. The continuity, accountability, and monitoring backbone scored 14. Restaurant and hotel organics scored 13, while institutional and commercial recyclables scored 11. Neighbourhood organics pilots and public-space and difficult fractions each scored 9 (Table 2).

Second, raw totals did not determine the final order by themselves. Residual disposal control entered Phase 1 because weak downstream control still undermines all later diversion gains. Market organics capture remained the strongest early circular node, but it entered after the minimum control floor was recognized. This result is fully consistent with the screening rule established in Section 3.3.

Third, the matrix separates early nodes from later nodes clearly. Market organics, restaurant and hotel organics, and the continuity backbone are the main early transition components. Institutional and commercial recyclables are important, but less enabling for the first step. Neighbourhood organics pilots, public-space waste, and difficult fractions matter for later expansion, but remain harder to control under current service conditions. Table 2 therefore provides more than a shortlist. It defines a feasible entry order under Cusco's present constraint structure.

Sequenced transition pathway for Cusco

Table 3 and Figure 4 translate the screened nodes into a sequenced transition pathway. The resulting pathway contains three packages and five phases. Together, they preserve the logic established in Sections 2 and 3: control before expansion, controllable nodes before diffuse rollout, and continuity before large-scale replication.

Table 3: Sequenced intervention packages for organics-first transition in Cusco under disposal constraint

Package and Time Horizon	Main focus	Priority nodes	Priority actions
1. Minimum disposal control and data reliability (Immediate to short term)	Restore minimum downstream control and reduce immediate environmental risk	Haquire residual disposal	• Restore weighing and load records; • Re-establish routine cover, compaction, and access control; • Reactivate leachate treatment or interim control; • Strengthen fire, nuisance, and PPE controls; • Improve monitoring and short-term life-extension management.
2. Organics-first diversion at controllable nodes (Short to medium	Capture the most controllable organics flows first and reduce pressure on Haquire	Markets; restaurants and hotels; selected neighbourhood pilots; linked composting	• Start with market organics; • Extend to restaurants and hotels through schedule-compatible pickup; • Improve containers, punctuality, and temporary storage;

Package and Time Horizon	Main focus	Priority nodes	Priority actions
term)		routes	• Apply simple contamination rules; • Stabilize interim composting flows; • Expand to selected neighbourhood pilots only after service reliability improves.
3. Differentiated scale-up, continuity, and accountability (Medium term)	Protect early gains and support broader but selective expansion	Institutional and commercial recyclables; neighbourhood expansion; public-space and difficult fractions; monitoring and accountability backbone	• Institutionalize route monitoring, participation tracking, and satisfaction feedback; • Improve cost visibility and arbitrios-linked financing; • Define performance standards; formalize recycler and service-provider roles; • Expand cleaner dry-recyclables capture; • Introduce tailored approaches for households, public-space waste, and difficult fractions.

Source: This study, based on evidence streams listed in Table 1

Package 1 reduces immediate environmental risk and restores the minimum control floor needed for later reform. Package 2 diverts the most controllable organics flows and helps reduce pressure on Haquire. Package 3 protects continuity and supports broader but selective expansion through cleaner recyclable capture, tailored household and public-space strategies, monitoring, finance, and accountability.

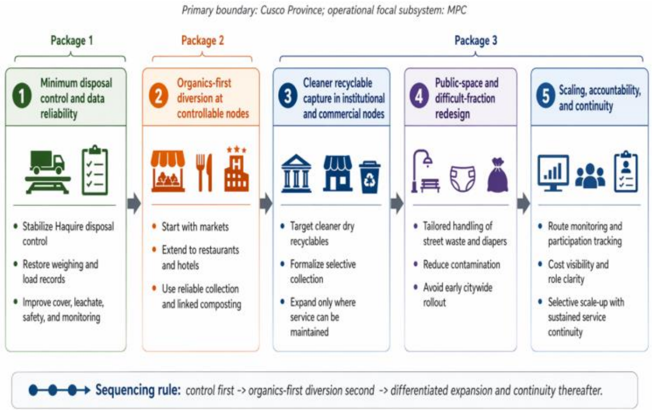

Figure 4: Node-based sequenced transition pathway for Cusco Province

Figure 4 makes the phase logic explicit. Phase 1 establishes minimum disposal control and data reliability. Phase 2 expands organics pilots in controllable nodes. Phase 3 adds cleaner recyclable capture in institutional and commercial streams. Phase 4 addresses difficult fractions and public-space redesign. Phase 5 consolidates scaling, accountability, and continuity. Read together, Table 3 and Figure 4 show that Cusco's pathway is not an undifferentiated circular-economy package. It is a constrained sequence shaped by one dominant result: the downstream end of the system remains weaker than the front end.

DISCUSSION AND POLICY IMPLICATIONS

Section 4 showed that Cusco's main constraint is not lack of material opportunity. It is weak downstream control, uneven node conditions, and fragile continuity. This section interprets those findings and then translates them into practical implications for sequencing and implementation.

Disposal control as the enabling condition

Figure 2 shows why disposal control must come first. Cusco's waste problem is no longer only a generation problem. It is a pathway problem. Most waste still moves through a weak residual chain. As a result, front-end gains do not yet translate into strong environmental outcomes (DGGRS, 2025; MINAM, 2025; OEFA, 2023).

This finding changes the meaning of circular transition in Cusco. Under current conditions, more separation alone would not resolve the system's main weakness. It could reduce pressure on Haquire, but it would not remove the central risk created by weak downstream control. Recent reviews also show that circular progress loses environmental force when treatment and disposal remain weak (Awino & Apitz, 2024).

The April 2024 field record strengthens this interpretation. It documented neglected site management since 2019, the stoppage of leachate treatment, and continued reliance on recirculation. It also recorded municipal concern about remaining site life and the need to reduce incoming waste quickly. These details are central to the interpretation. They explain why residual disposal control entered Phase 1 in Table 2 and Package 1 in Table 3 (Project field-visit records April–May, 2024).

This result also clarifies the study's contribution. The framework supports organics-first reform, but only under defined enabling conditions. In Cusco, circular transition becomes credible after a minimum control floor is restored at the downstream end. Disposal control is therefore an enabling condition, not a parallel issue.

Why organics-first reform should begin at selected nodes

Figure 3 and Table 2 show that organics remain the strongest early diversion opportunity, but not every organics node is equally suitable. Markets, restaurants, and hotels stand out because they combine high organics yield with stronger operational controllability than diffuse citywide household rollout (MPC, 2024a, 2024b).

Markets are the clearest first node. Their waste is heavily food-dominant, spatially concentrated, and easier to schedule. They therefore offer the best early test of route discipline, contamination control, and visible diversion gains. This explains why market organics capture received the strongest screening result in Table 2.

Restaurants and hotels form the next logical node. Their organics yields are lower than markets, but still substantial. More importantly, many have defined staff, storage routines, and predictable operating cycles. Those conditions make quality control more realistic than in diffuse household systems. However, the August interviews also show that willingness depends strongly on punctual collection and suitable schedules (Project stakeholder interviews August, 2024).

This distinction matters for implementation. The August interviews suggest that users were not necessarily resistant, but their participation was conditional. Some restaurants had separated before, but stopped when pickup became irregular. Some residents were already separating, but lost motivation when waste was later remixed in the compactor. Others asked for storage-fit schedules, containers, and visible feedback. Participation was therefore present, but fragile (Project stakeholder interviews August, 2024).

This is why neighbourhood organics pilots were placed later than markets and service-sector nodes. Household expansion is important, but it is operationally harder. It depends on route reliability, repeated communication, storage convenience, and stronger trust that separation will be preserved. Without those conditions, household programmes can expand symbolically while remaining materially weak.

The same logic applies to non-organics nodes. Institutional and commercial recyclables are promising because cleaner dry materials can be captured there more reliably than in mixed household streams. By contrast, public-space waste and difficult fractions require a different service logic. They are necessary for later performance, but they are not strong early circular entry points.

From diagnosis to transition design

A central contribution of this study is the conversion of diagnosis into reform order. Table 2 screens candidate nodes against urgency, flow leverage, readiness, controllability, enabling role, and feasibility. Table 3 then groups the stronger nodes into linked packages, while Figure 4 visualizes their phase logic. The contribution therefore lies in moving from evidence description to operational prioritization.

This step matters because many municipal waste plans move directly from problem description to broad expansion language. In disposal-constrained systems, that jump can weaken implementation and leave programmes fragmented. Cusco's evidence suggests exactly that risk. The city already has selective collection experience, composting routes, recycler links, and willing participants. Yet those elements remain limited in scale and continuity under current operating conditions (MPC, 2024b; Project field-visit records April–May, 2024).

The framework therefore adds a missing middle step. It asks which nodes are ready, controllable, and system-enabling before wider scale-up is attempted. This is why continuity, accountability, and monitoring appear as a cross-cutting node in Table 2 and as part of Package 3 in Table 3. In Cusco, pilot activity exists, but routine conversion remains weak.

The field evidence supports the same reading. Municipal meetings described temporary promoters, limited budget continuity, and the need for annual satisfaction checking. Interviews described discouragement when separated waste was later mixed, when pickup times were unsuitable, or when communication was weak. These findings suggest that the main barrier is not awareness alone. It is the weak translation of awareness into reliable service (Project field-visit records April–May, 2024; Project stakeholder interviews August, 2024).

Figure 4 should therefore be read as an implementation logic. Phase 1 reduces immediate downstream risk. Phase 2 builds credibility through controllable organics nodes. Later phases widen the system only after early routines become stable.

Policy and implementation implications

The practical implication is a sequenced implementation pathway rather than an unstructured action list. Cusco should first restore minimum disposal control, then stabilize early organics nodes, and only later widen the system through differentiated expansion and stronger continuity mechanisms.

The first priority is operational control at Haquire. Cusco needs reliable weighing, load records, routine cover, compaction, access control, interim leachate management, and stronger nuisance and fire control. These measures are basic, but they improve both environmental protection and planning reliability.

The second priority is protected early diversion at controllable nodes. Market organics should remain the first circular node. Restaurants and hotels should follow by zone and schedule, not by scattered enrolment. The August interviews show that willingness exists, but participation depends on punctual pickup, suitable time windows, and clear communication (Project stakeholder interviews August, 2024). Expansion should therefore be service-led rather than awareness-led.

The third priority is quality-led recovery. Cleaner recycling should focus first on institutional and commercial streams, where Figure 3 already shows stronger dry-recyclable signatures. This can improve output quality and reduce sorting burden before broader expansion is attempted.

The fourth priority is tailored management of difficult fractions and public-space waste. Table 2 correctly places these after the cleaner early nodes. Diapers, mixed public-space waste, and other contamination-prone fractions need different service rules from market organics or clean recyclables.

Governance upgrades must run alongside these physical actions. Shared downstream assets require clearer planning, cost logic, and performance standards across jurisdictions. Monitoring should begin with a small operational set, including site inflow, organics captured by node, route punctuality, contamination or rejection, participation continuity, and basic user satisfaction.

Private participation may help at selected nodes, but only as a capability tool. It is most relevant for technically demanding functions such as engineered disposal, transfer, facility operation, or monitoring systems. In Cusco, it should follow a clear public strategy and credible oversight, not substitute for them.

Wider relevance for similar cities

The Cusco case has wider relevance, but that relevance is conditional. The framework is not a universal template.

Cities with high collection coverage but weak downstream control should not treat front-end service reach as a proxy for overall system performance. The Cusco case shows that strong waste capture can coexist with uncontrolled disposal and weak recovery. In such settings, the first diagnostic task is to examine the residual pathway before moving from control to diversion.

The Cusco case also shows that organics-first transition is justified where organics dominate the waste stream, but only if it is linked to minimum downstream control. Organics create the strongest early diversion opportunity, yet weak disposal still shapes the whole system. For similar cities, the practical implication is to begin with controllable organics nodes that can reduce residual pressure early, while recognizing that this lesson is less transferable where organics are not dominant or treatment outlets are absent.

A third lesson concerns heterogeneity. Province-wide averages can hide important differences in diversion potential, contamination burden, and service needs across districts and generators. Transition design should therefore be differentiated rather than average-based. Cities should use district and generator profiles to distinguish early nodes, later nodes, and difficult streams. This lesson is most useful where at least basic composition evidence is available by place or generator.

A fourth lesson concerns governance around shared downstream assets. The Cusco case shows that front-end service can continue while shared disposal and treatment functions remain weakly coordinated. Shared-asset governance should therefore be treated as a reform priority rather than a background condition. For cities where several districts depend on common disposal or treatment assets, this implies the need for joint planning, cost-sharing, performance standards, and monitoring across jurisdictions.

A fifth lesson concerns behaviour and service reliability. Cusco shows that willingness alone is not enough. Participation weakens when pickup is irregular, schedules are unsuitable, storage is difficult, or separated waste is later mixed. Similar cities should therefore match schedules, containers, storage conditions, and feedback systems to each target node. This is especially important in tourism, commercial, and dense urban service settings, where participation depends strongly on operational fit.

The Cusco case also shows that laws, plans, and reporting systems can improve faster than physical outcomes. Where the policy framework is moderate but local delivery remains weak, reform should focus on implementation capacity rather than on new policy instruments alone. The practical implication is to convert reporting and planning into routine operational decisions, accountability, and finance. This lesson is especially relevant where legal reform already exists but implementation remains uneven.

Another lesson concerns pilot continuity. Small programmes can exist for years without changing the system materially. Pilots should therefore be converted into monitored, financed, and scalable routines. In practice, this means adding continuity mechanisms early, including route monitoring, participation tracking, and defined roles. This lesson is most relevant where programmes rely on temporary staff or unstable budgets.

Finally, not all streams should enter transition in the same way or at the same time. Cusco shows that streets, diapers, and other difficult fractions require different service logic from organics or clean recyclables. Similar cities should therefore apply tailored public-space, sanitary-fraction, and contamination-control strategies only after cleaner early nodes are stabilized. This is especially important where contamination risk is high and enforcement is weak.

Taken together, these lessons are diagnostic and conditional rather than universal. They are most transferable to cities with organics-dominant waste streams, disposal constraints, uneven implementation capacity, and fragmented governance across collection and downstream assets. For such cities, the main practical implication is clear: begin with system diagnosis, move through differentiated node selection and minimum control, and only then pursue broader scale-up under stronger continuity and accountability conditions.

Limitations

This study has four main limitations.

First, the evidence base is uneven across scales. Province-level series were stronger for time trends and pathway dependence, while MPC-level evidence was stronger for generator profiling and early-node identification. This design was appropriate for transition diagnosis, but it limited full like-for-like comparison across all scales.

Second, some key datasets were cross-sectional rather than longitudinal. District and generator composition evidence was most detailed for 2024, so heterogeneity was analyzed mainly as a current structural condition rather than as a multi-year dynamic. The framework therefore identifies priority nodes under present conditions, but does not test whether those node signatures remain stable across years.

Third, some operational variables could only be assessed indirectly. Disposal control, pathway dependence, and selective recovery were supported by strong official and oversight evidence, but full weighed and node-specific mass balance remained limited. This is especially relevant where downstream records are incomplete or operational monitoring has been weak. The resulting sequence is therefore evidence-based, but still constrained by the quality of the underlying administrative system.

Fourth, the field materials were used for triangulation and feasibility checking, not as statistically representative survey evidence. The April meetings and August interviews were valuable for interpreting service reliability, participation conditions, and implementation bottlenecks. However, they should not be read as population-wide measurement of behaviour or preferences.

These limitations do not weaken the study's central conclusion. The evidence is still strong enough to identify the main bottleneck, distinguish stronger and weaker early nodes, and justify a sequenced transition logic. However, the framework should be understood as a decision-support tool rather than a predictive model, a full engineering design, or a cost-optimization exercise.

Future work should deepen the transition design with better weighed flow data, repeated generator and district characterization, route-level operational records, and node-specific monitoring of contamination, rejects, and participation continuity. It should also test how the proposed sequence performs when linked to engineering design, financial appraisal, and implementation monitoring over time.

CONCLUSIONS

This study developed a multi-scale prioritization framework for organics-first reform in Cusco under disposal constraint. The framework moved from system diagnosis to transition design by linking province-level pressure, district and generator heterogeneity, field-verified feasibility, and sequenced intervention logic.

The results show that Cusco's central constraint is not lack of material opportunity. It is the combination of rising waste pressure, persistent organics dominance, and weak downstream control. Waste increased markedly during 2019–2024, while the downstream pathway remained overwhelmingly dependent on non-sanitary dumping. This made disposal control the binding system constraint.

The results also show why average-based planning is insufficient. Districts and generators differed strongly in organics yield, recyclable quality, contamination risk, and service-design needs. Markets emerged as the strongest early organics node. Restaurants and hotels formed the next practical tier. Institutional and commercial streams offered cleaner recycling opportunities, while public-space waste and difficult fractions required a different service logic.

The paper's main contribution is therefore practical as well as analytical. It shows how waste diagnosis can be translated into a defensible reform sequence for a disposal-constrained, organics-dominant city. More broadly, the Cusco case suggests that similar cities should not begin transition from generic expansion. They should begin from system diagnosis, then move through differentiated node selection, minimum control, and only later broader scale-up under stronger continuity and accountability conditions.

Authorship contribution statement

Md Abu Bakar Siddique: Writing – Original draft, Methodology, Conceptualization, Formal Analysis. **Seungdo Kim:** Supervision, Funding acquisition, Conceptualization, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The data supporting this study come from official public databases, municipal documents, and project records. Publicly accessible sources are cited in the article. Additional compiled data and harmonized analytical files are available from the corresponding author on reasonable request.

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