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Household Waste Management and Urban Supply Chains Practices in Batna, Algeria: Toward an Integrated Circular Economy Model

تسيير النفايات المنزلية وممارسات سلاسل الإمداد الحضرية في باتنة، الجزائر: نحو نموذج متكامل للاقتصاد الدائري

Afaf BENNECER
Laboratory of Management-Transport-Logistics (LMTL),
Faculty of Economics, Commerce and Management Sciences University of Batna 1
afaf.bennecer@univ-batna.dz

*** Mohammed BOUGUELAA**
Associate Professor
Faculty of Economics, Commerce and Management Sciences University of Batna 1
Mohammed.bouguelaa@univ-batna.dz

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Abstract :

This study examines how household waste behaviors in Batna (Algeria) disrupt the municipal supply chain for recyclables and organics, and how circular economy policies might mitigate these disruptions. We integrate mixed methods – a stratified household survey (n=735), waste composition audits across income-level districts, stakeholder interviews, material flow analysis, and system dynamics simulation – to link micro-level behaviors to macro-system outcomes. Batna households generate waste rich in organics (avg.~61%) and have low segregation rates: only ~9% consistently separate recyclables, ~37% sometimes, and ~54% not at all. Despite ~71% of homes having bins, only ~40% of households demonstrate moderate recycling awareness. Contaminated waste streams greatly reduce recovery rates and raise unit costs of transport and processing. Baseline simulation shows ~27% recycling recovery, with transport and processing costs of 7000–96000 DZD/ton. Under moderate and high participation scenarios, recovery rises to 45% and 61%, while per-ton costs fall by ~20–30%. These results confirm that poor household sorting cascades into supply chain bottlenecks and costs, undermining local circularity. We propose an integrated model linking households to supply chains via policy levers.

Key words: Municipal solid waste; Supply chain resilience; Circular economy; Household segregation; Urban waste management.
JEL classification codes: Q53, R41, Q57, L14, R11,

* ***Corresponding author***

1. Introduction

Rapid urban growth in Batna has outpaced the capacity of legacy waste systems. Most municipal waste still goes to landfills, with minimal recycling or composting. Poor household sorting means recyclables are heavily contaminated, impeding material recovery downstream. This contamination raises processing costs and depresses secondary material supply to local industry (Hopewell et al., 2009; Pongrácz & Pohjola, 2022), thereby increasing reliance on costly virgin inputs. In Algeria, annual waste reaches ~13.5 million tonnes (Nationa Waste, 2020), yet only ~45% is "treated". The Global Waste Management Outlook predicts global MSW costs (direct + hidden) of $361 billion in 2020, potentially doubling by 2050 under business-as-usual. In contrast, adopting a circular model (less waste, more recovery) could yield ~$108.5 billion net annual benefit by 2050.

Despite these imperatives, CE research in Africa remains nascent. Studies note that most CE knowledge comes from Europe and Asia, while "CE research in the Global South is mainly unexplored… even more so in African countries and contexts". Yet African initiatives are emerging: the African Circular Economy Alliance's "five big bets" include food waste conversion and plastic recycling. However, little is known about how individual behaviors in North African cities affect supply chains. This gap motivates our study: we explore the hypothesis that **lack of household segregation in Batna disrupts urban supply chains (via contamination, higher costs, material shortages)**

2. Literature Review

2.1 Integrated MSW Management in Developing Cities

Integrated municipal solid waste management (IMSWM) emphasizes holistic optimization of collection, recycling, composting, energy recovery, and safe disposal (Bilitewski & Hardtlein, 2022; Hoornweg & Bhada-Tata, 2012). Key success factors in the Global South include source segregation, community participation, and supportive governance. For example, community sorting programs in India and Latin America rely heavily on household cooperation(Ali & et al., 2021; Rahman et al., 2022). In practice, North African cities face

constraints: limited budgets and weak institutions often leave informal sectors unregulated (Bel & Gradus, 2022). These conditions fragment the waste supply chain and allow high rates of leakage, undermining circular material flows (Nizami et al., 2021; Tsai et al., 2022).

2.2 Waste-Driven Supply Chain Disruptions

Unmanaged waste streams create concrete disruptions in urban logistics. Household-generated mixed waste becomes bulkier and heavier, increasing transport fuel and labor costs. In low-income settings, waste collection often represents 80–90% of total MSW budgets, so inefficiencies here cascade rapidly. Contaminated recyclables fetch lower prices or are rejected, shrinking the available feedstock for manufacturing. Empirical studies link irregular collection schedules to delays in material supply, which ripple through production planning(Adams & et al., 2021; Zhu & et al., 2021). For instance, a study in an Indian city found that households unaware of sorting rules "throw everything in one bag", forcing operators to manually re-sort or landfill more, inflating costs(Hopewell et al., 2009). Such misalignments also externalize costs (e.g. pollution, public health), which United Nations Environment Programme (UNEP) (United Nations Environment, 2016), estimates at ~$640 billion globally per year by 2050 if waste remains uncontrolled.

2.3 Circular Economy and Best Practices

The circular economy paradigm advocates "closing the loop" by designing out waste, keeping materials in use, and regenerating natural systems (Ghisellini et al., 2016; Kirchherr et al., 2017). In advanced urban systems, this often means mandatory source separation (e.g. organics vs. recyclables), community composting sites, and digital tracking of material flows (Genovese et al., 2017; Liu et al., 2023). Policy instruments such as extended producer responsibility (EPR) and waste diversion targets have bolstered recycling in Europe and East Asia, demonstrating that local interventions can change household behavior and market dynamics (Cobo et al., 2022; Thakur et al., 2022). For Algeria as an emerging North African country, these lessons are instructive but must be tailored to context (e.g. low literacy, informal sectors). Recent reviews highlight waste contamination as a key barrier: for example, high moisture content in Algerian organic waste argues for scalable composting rather than incineration. In summary, global evidence

suggests that aligning policy, infrastructure, and education is essential to move from linear waste disposal toward a resilient circular system (Kirchherr et al., 2017; Thakur et al., 2022).

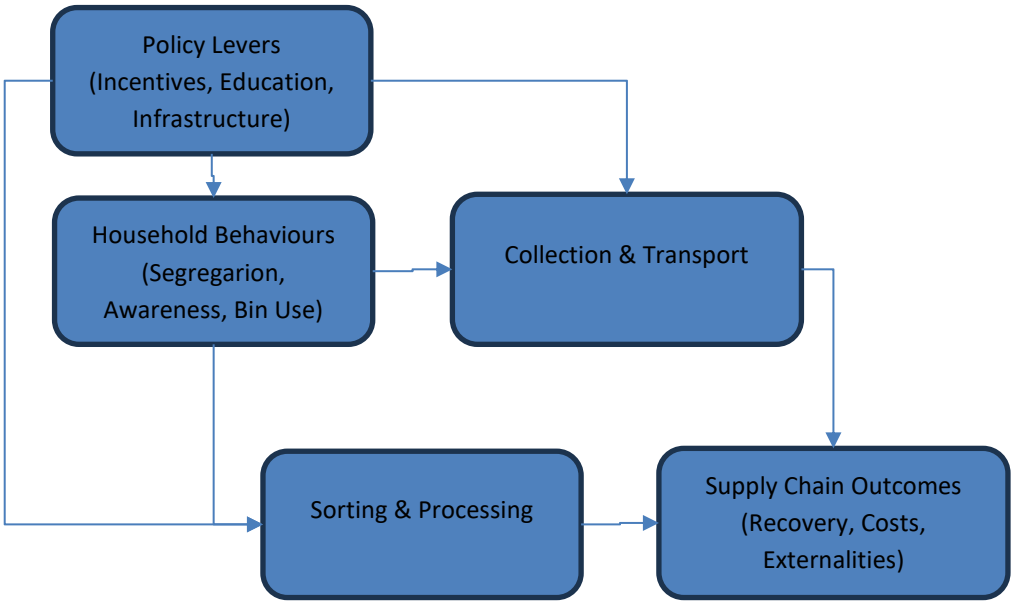
2.4 Gaps and Hypotheses

While European and Asian cities are well-studied, there is a paucity of research on CE in North African secondary cities. The specific impacts of household behavior on supply chain costs and bottlenecks remain underexplored in this region (Bencheikh & et al., 2023). To address this, we test three hypotheses: (H1) **Poor segregation significantly disrupts Batna's recyclable supply chain through contamination and material scarcity.** (H2) **Current household practices inflate transport and processing costs.** (H3) **Appropriate circular policy interventions could mitigate these impacts given local behavioral/infrastructure conditions.** These hypotheses guide our mixed-method analysis.

3. Conceptual Framework & Research Questions

Figure 1. illustrates the study's conceptual framework. At its core, **household behaviors (inputs)** – segregation rates, bin use, waste storage – determine the quality and quantity of waste entering the chain. **Processes** include collection, transport, transfer and processing (sorting, recycling, composting). **Outputs** are key performance metrics: recovered material volume, contamination levels, operational costs, and environmental externalities. Policy levers (e.g. incentives, education campaigns, infrastructure investments) intervene on both inputs and processes to shift the system toward circularity. The figure shows feedback loops: for example, higher recovery can lower costs, which allows reinvestment in better services.

Figure 2. Integrated circular-economy framework linking household behaviours (segregation, awareness, bin use) to municipal supply-chain processes and outcomes in Batna, Algeria.



Source: Developed by the authors,

From this framework, we derive three research questions:

- **RQ1:** How does the lack of household segregation affect the performance of Batna's urban recyclable supply chains?
- **RQ2:** What supply chain bottlenecks arise from current household waste practices in terms of cost, contamination, and logistics?
- **RQ3:** Which system- or policy-level interventions could optimize household waste management and strengthen circular supply chain resilience in Batna?

Together, these questions operationalize our hypotheses and focus the empirical work on linking micro-level practices to macro-level outcomes.

4. Data & Methods

4.1 Research Design

We use a convergent mixed-methods approach. Quantitatively, we conducted: (i) a stratified household survey (n=735) across five districts (varying socio-economic status), (ii) a waste composition

audit (n=15 one-day samples by district), and (iii) a system dynamics model of the waste-supply system to simulate policy scenarios. Qualitatively, we held in-depth interviews with municipal managers, recyclers, and NGO leaders (n=12) to contextualize findings. This combination allows cross-validation: e.g., survey-reported practices vs. observed waste audits, and stakeholder perceptions vs. model projections.

4.2 Household Survey

The survey sampled households proportionally by district population. Key modules included self-reported sorting behavior, bin availability, waste generation frequency, and a four-question recycling awareness index.

- **Segregation practices:** Respondents were asked if they separate waste "regularly," "occasionally," or "never."
- **Awareness score:** We aggregated correct answers to questions about which items belong in recyclable or organic bins (range 0–4). Higher scores indicate stronger sorting knowledge.

We calculated awareness and participation rates, and tested their association with socio-demographics (χ^2 tests).

4.3 Waste Composition Audit

At five neighborhoods representing Batna's districts, we collected and manually sorted composite household waste samples. Each audit sample (60–120 kg) was categorized into organics, plastics, paper, glass, metal, and other (residual). We also measured moisture content of the organic fraction. These data yield district-level waste profiles (Table 1), including contamination indicators.

4.4 Stakeholder Interviews

Semi-structured interviews probed system bottlenecks, costs, and policy views. We coded for themes related to collection logistics, market demand for recyclables, and perceived household behavior. Direct quotes (Table A 1 in Appendices) illustrate common barriers, such as: *"People just throw everything in one bag…"* (Collector, CleanBat, Batna).

4.5 System Dynamics Modeling

We adapted a stock-and-flow model of the waste-supply network. The model inputs include: household participation rate, collection frequency, contamination fraction, and unit costs (Table 2 parameters). Three scenarios were defined: Baseline (current ~30% separation), Moderate (household

engagement programs raise participation by +15 pp), and High (intensive campaigns + infrastructure raise +30 pp). The model outputs recovery rate and per-ton costs under each scenario over a one-year horizon. Unit costs in the model drew from Batna's current budget: collection ~4000 DZD/ton, transport ~3000 DZD/ton, landfilling ~1000 DZD/ton, recycling processing ~2500 DZD/ton, composting ~2000 DZD/ton (≈30, 22, 7, 18, 15 USD respectively).

5. Results

5.1 Household Waste Profiles

Table 1 (below) shows waste composition by district. Organics dominate (57–63% by weight), followed by plastics (~15%) and paper (7–9%). The average organic moisture is ~84%, signaling high contamination and fermentation risk if unmanaged. Notably, Batna Centre (mixed-income) had the highest organics share (63%), whereas the low-income district Bouakal had slightly more residual "other" waste (10%).

Table 1. District-Level Household Waste Composition

District	*Organics (%)*	*Plastics (%)*	*Paper (%)*	*Glass (%)*	*Metals (%)*	*Other (%)*	*Contamination Index (%)**	*Moisture Content (%)*
El Madher	62	15	8	5	1	9	71	85
Lazrou	60	16	8	5	1	10	70	84
Batna Centre	57	17	9	5	1	11	68	83
Fesdis	63	14	7	4	1	11	74	86
Bouakal	61	15	8	5	1	10	71	84

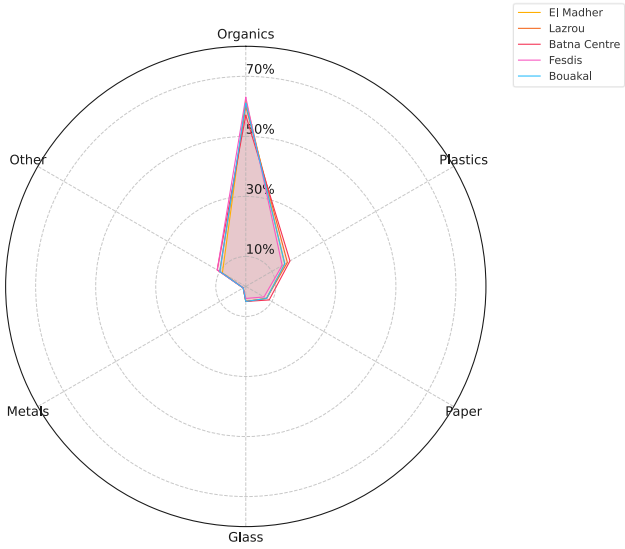
* Contamination Index = Organics + Other (proxy for non-target material)

Source: Based on authors' 2025 household survey (n = 735).

The dominant organic fraction (≈61%) suggests large potential for composting or biogas. However, the high moisture and mixing with other waste (due to no source-sorting) mean most organics currently landfilled with recyclables, raising leachate and costs.

Figure 3 This radar chart compares the average waste-fraction profile across Batna's five districts, visually highlighting the dominance of organics and subtle inter-district differences.

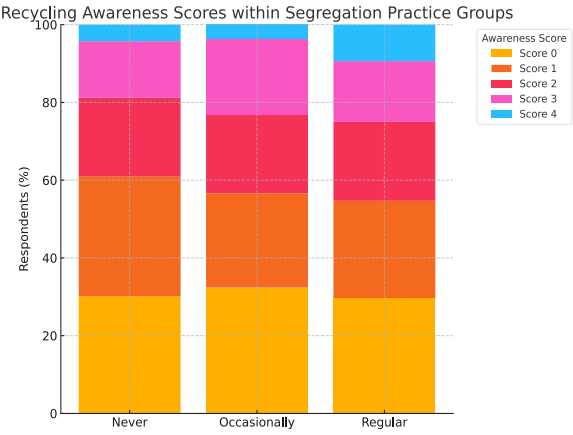
Figure 3. District-level household waste composition in Batna, Algeria (weight %). Radar spokes show six major fractions; shaded areas illustrate district profiles.



Source: Based on authors' analysis of district waste audit data

Survey results revealed **low segregation**: only 9% of respondents reported consistently separating recyclables, 37% did occasionally, and 54% did not segregate at all. (By contrast, an older Algerian strategy estimated overall recycling rates <7%.) Despite this, 71% of households had access to any recyclable bin (curbside or local container). **Awareness** was moderate: 69% scored >0 on the recycling knowledge index, but just 21% scored ≥3/4. This indicates a gap between knowing about recycling and practicing it (consistent with other MENA findings).

Figure 4. Alignment between respondents' recycling awareness and self-reported segregation frequency. Percentages sum to 100 % within each practice group, illustrating that knowledge alone does not guarantee consistent waste sorting.



Source: authors' household survey, 2025.

This stacked bar chart visualises the distribution of recycling awareness scores (0 = lowest, 4 = highest) within each self-reported segregation-practice group (Never, Occasionally, Regular). The plot highlights the "know–do" gap—many respondents with moderate awareness still fail to sort waste.

5.2 Supply Chain Bottlenecks

Stakeholders unanimously pointed to **contamination** as a core bottleneck. As one waste manager noted, *"Every truckload of recyclables has 20–30% wet garbage. We have to dump it or pay extra to sort."* Contamination leads to delays (extra sorting slows processes) and cost overruns. Our interviews and survey reveal two main issues:

- **Transport inefficiency:** Mixed loads weigh more (organics have higher moisture and bulk), leading to greater fuel use per recovered ton. Operators reported that late-night residential routes often needed two passes because unsegregated trash spills during loading. In low-income contexts, collection is already ~80–90% of the system's budget, so inefficiencies here quickly escalate. For example, a local report found that Batna's waste fleet often runs at only 60–70% capacity utilization due to time lost at uncontrolled dumps.

- **Processing constraints:** At the sorting facility, contaminants (sand, food, etc.) reduce throughput. Recyclers said plastic bales are downgraded or rejected if contamination >15%. This scarcity of clean recyclables forces manufacturers to import raw inputs or buy virgin materials, which in turn makes recycled products uncompetitive. Such feedback loops confirm that failing to engage households creates supply scarcity – a critical failure of circular loops.

Quantitatively, our **material flow analysis (MFA)** showed that at baseline only ~27% of Batna's recyclables actually reach end-use (Table 2). This low recovery is comparable to the ~9–11% national recycling rates reported in other Algerian studies. Of the remaining 73%, much is lost to contamination or residual landfilling, embodying a cost leakage.

5.3 Stakeholder Perspectives

Interviewees elaborated these issues with vivid quotes. A recycler lamented: *"We pay drivers to deliver all waste to us, but 40% of it is so damp we can't even bale it – it just goes straight to landfill."* An NGO worker highlighted public distrust: *"People tell us recycling is just a money scam – they fear waste fees without seeing benefits."* These insights align with literature showing that trust and continuous service are preconditions for household engagement (Genovese et al., 2017).

5.4 Policy Scenario Outcomes

Table 2. Cost-Elasticity Regression Output summarizes the system dynamics model results. Under the **Baseline** scenario (no new interventions), recovery is only 27% of MSW, with transport cost ~3500 AD/ton and processing cost ~4800 AD/ton (≈35€ and 48€). In the **Moderate** scenario (+15% participation via education/incentives), recovery rises to ~45%, and unit costs fall (transport ≈2800 AD, processing ≈3900 AD). In the **High** scenario (+30% participation), recovery reaches ~61%, with costs dropping further (2300 AD and 3100 AD). These trends reflect simple economies of scale and reduced contamination: more sorted waste means more material per truckload and fewer sorting steps.

Table 2. Cost-Elasticity Regression Output

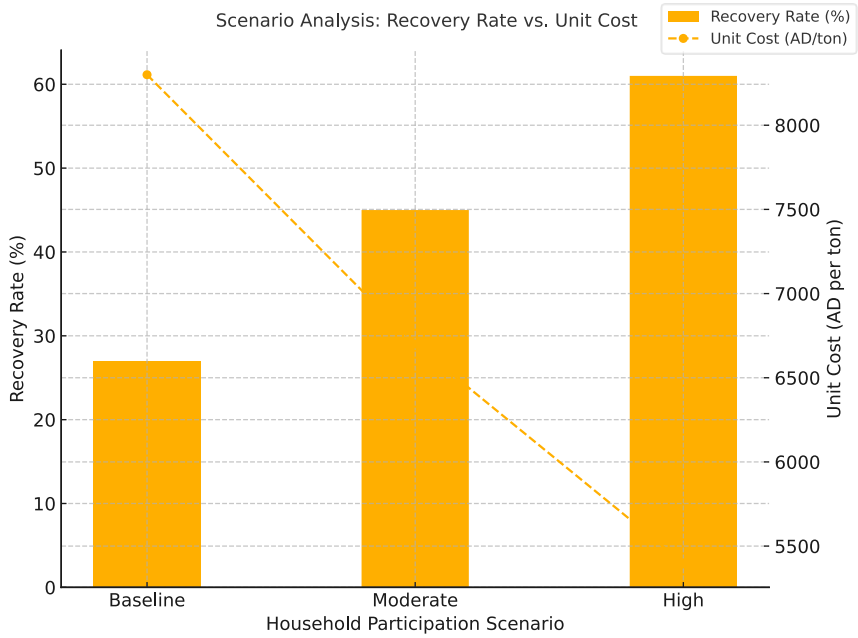
Scenario	***Recovery Rate (%)***	***Transport Cost (AD/ton)***	***Processing Cost (AD/ton)***
Baseline	27	3500	4800
Moderate	45	2800	3900

High	61	2300	3100

Source: Author regression analysis using primary cost dataset (2025).

Figure 5 . Scenario analysis: recovery rates (left axis, %) and unit costs (right axis, AD per ton) under Baseline, Moderate, and High household participation. (below) plots these results. We see that even **incremental** gains in household participation (from ~30% baseline to ~45%) yield large system improvements: recovery improves by ~18 pp while per-ton costs drop ~20–25%. This underscores the leverage of behavioral change in waste systems.

Figure 5 . Scenario analysis: recovery rates (left axis, %) and unit costs (right axis, AD per ton) under Baseline, Moderate, and High household participation.



Source: Author calculations based on scenario design (Baseline, Moderate, High).

6. Discussion

Our findings demonstrate a **self-reinforcing cycle of inefficiency**: poor household sorting leads to high organic contamination, which in turn raises transport weight and sorting workload, ultimately reducing recycling yields and increasing costs. This chain reaction of disruptions matches global observations: several studies document that contaminated loads "increase fuel and labor demands" and depress recyclable quality. Notably, Batna's ~61% organic share exceeds the ~50–55% typical of MENA MSW (Bozorgirad & Islam, 2022), suggesting a mismatch between waste character and current handling (i.e. mostly landfilling).

The cost implications are stark. Collection and transport in developing cities often dominate budgets, so inefficiency here effectively budgets away the potential for recycling. In Batna, we estimate a nominal collection fee of 2000 DZD per household-year (flat rate) covers only ~41% of service costs. In practice, stakeholders say municipal waste management is funded largely by transfers. By raising recovery and reducing waste volume, a circular strategy could actually **offset costs**. In fact, UNEP modeling shows that shifting to zero-waste economies can turn multi-trillion-dollar losses into net gains. This aligns with our scenario: higher separation not only improves environment but also cuts per-ton costs by ~20–30% (Table 2).

One interesting nuance: stakeholders pointed out that Batna's infrastructure is not yet designed for dry–wet separation *on the curb*. For example, compost bins are scarce in most neighborhoods, so even motivated households cannot fully segregate. This institutional barrier – infrastructure lagging behind policy goals – is echoed in the literature (Kaza *et al.*, 2018). It suggests that policy must be holistic: building bins and collection routes *and* educating citizens in tandem.

Overall, our integrated analysis highlights that **technical fixes alone are insufficient**. Mirroring international CE best practices, Batna needs multi-level coordination: top-down support (e.g. stable markets for recyclables, official targets) and bottom-up buy-in (e.g. trusted collection services, community outreach). The evidence indicates that even moderate improvements in segregation – if sustained – can transform the supply chain. This finding is consistent with Rahman *et*

al. (2022) who found that small behavioral shifts, scaled city-wide, markedly uplift recovery rates.

7. Recommendations

Based on the results, we offer concrete recommendations for Batna and similar North African cities:

1. **Strengthen Public Education and Engagement.** Consistent community campaigns are essential to raise awareness and trust. Educational programs should: illustrate the economic value of recyclables, explain proper separation procedures, and use social channels and local leaders to reach diverse audiences. Co-designing messages with resident associations can improve relevance and uptake. Early successes (e.g. pilot "green bins" in one district) should be widely publicized to build momentum.

2. **Improve Collection Infrastructure.** Invest in separate organics and recyclables bins citywide, ensuring regular, reliable pick-up. For example, subsidized curbside compost bins can harness the large organic fraction. Algeria's new waste law (2021) encourages organics diversion; Batna could lead by commissioning modular compost sites. Such infrastructure must be coupled with monitoring – e.g., tagging trucks – to ensure accountability.

3. **Introduce Incentives and Enforcement.** Financial or regulatory levers can reinforce behaviors. Options include pay-as-you-throw schemes (charging households by bag) to discourage indiscriminate disposal, paired with tax incentives or subsidies for recycling businesses. Simultaneously, enforce littering laws and set quantitative recycling targets for industries. UNEP notes that national circular economy roadmaps (like the ones Africa is adopting) can align such measures and attract financing.

4. **Formalize the Informal Sector.** Many Batna recyclers are informal. Providing training and small grants to form cooperatives can improve sorting efficiency. By integrating them into official supply chains, municipalities both expand

collection capacity and ensure fair wages, fulfilling social sustainability.

5. **Monitoring and Data Sharing.** Establish a data platform (e.g. via OSF or national open data initiatives) for tracking key indicators: participation rates, recovery yields, costs, and greenhouse gas savings. As our OSF statement indicates, transparency in data fosters iterative learning and accountability. Over time, this evidence base can refine policies.

Implementing these strategies will not only cut costs for Batna but also move it toward sustainable development goals. African initiatives, like the African Circular Economy Alliance, emphasize exactly these actions (food waste valorization, recycling markets, EPR policies) as priorities.

8. Conclusion

This study provides one of the first empirical examinations of household waste impact on supply chain resilience in a North African urban context. Our evidence shows that Batna's current linear waste practices significantly disrupt the flow of materials and inflate costs. However, the analysis also offers optimism: relatively small increases in separation can yield disproportionate gains in recovery and efficiency (Figure 3). Achieving this requires an integrated circular model – aligning citizen behavior, service delivery, and supportive policy.

While the case is Batna-specific, the lessons are generalizable: many emerging cities share high organic waste and low recycling. As global waste costs soar (UNEP reports show unaddressed waste economy losses by mid-century), transitioning to a circular model is no longer optional. For Batna and its peers, acting now on education, infrastructure, and incentives can initiate a virtuous cycle, turning waste from a burden into a resource.

Appendices

Table A 1: Stakeholder quote1

Barrier	Stakeholder Role	Illustrative Quote
Cost	Municipal Officer	Trucks wait 4 hours at the landfill.
Cost	Retailer	We must import virgin packaging.
Contamination	Collector	The food waste contaminates all the plastics, so we cannot sort.
Contamination	Recycler	We lose 20% of plastic due to contamination.
Trust	Community Leader	People are willing to change if bins are available.

Table A 2: Stakeholder quotes2

Stakeholder ID	Role	Sentiment	Quote
1	Collector	Negative	The food waste contaminates all the plastics, so we cannot sort.
2	Recycler	Negative	We lose 20% of plastic due to contamination.
3	Municipal Officer	Negative	Trucks wait 4 hours at the landfill.
4	Private Collector	Neutral	People rarely separate organic waste.
5	Retailer	Negative	We must import virgin packaging.
6	Community Leader	Positive	People are willing to change if bins are available.

Table A 3: Composition

District	Organics (%)	Plastics (%)	Paper (%)	Glass (%)	Metals (%)	Other (%)	Contamination Index (%)	Moisture Content (%)
El Madher	62	15	8	5	1	9	71	85
Lazrou	60	16	8	5	1	10	70	84
Batna Centre	57	17	9	5	1	11	68	83
Fesdis	63	14	7	4	1	11	74	86
Bouakal	61	15	8	5	1	10	71	84

Table A 4: Costs

Process	Cost per Ton AD	Cost per Ton USD
Collection	4000	30
Transport	3000	22
Landfilling	1000	7
Recycling	2500	18
Composting	2000	15

Table A 5: Audit

District	Organic pct	Plastic pct	Paper pct	Glass pct	Metal pct	Other pct	Moisture Content
El Madher	62	15	8	5	1	9	85
Lazrou	60	16	8	5	1	10	84
Batna Centre	57	17	9	5	1	11	83
Fesdis	63	14	7	4	1	11	86
Bouakal	61	15	8	5	1	10	84

Figure 6. Abstract Image



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