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An Optimization Model for Collaborative Location–Allocation of Recyclable Household Solid Waste: A Case Study in Cerro Navia and Quinta Normal in Santiago, Chile

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***Abstract*—This study applies a mixed-integer linear programming model to solve the location-allocation problem for recyclable household waste bins in the communes of Cerro Navia and Quinta Normal in Santiago, Chile. The model determines optimal bin locations at public spaces and assigns residents to collection sites within a maximum walking distance. Three scenarios are evaluated: individual planning for each commune separately and a collaborative scenario promoting inter-municipal cooperation. Results show that collaboration reduces infrastructure costs by 1.2% (USD$2,400) while improving average walking distance by 4.6% and increasing bin utilization from 85% to 87.3%. Sensitivity analysis reveals that the participation rate drives system scale linearly, while the maximum number of bins per site is not a binding constraint. Collaboration generates savings at all tested participation levels. The findings suggest that joint optimization of collection networks across the boundary between both municipalities can improve both cost efficiency and service accessibility without additional investment.**

Keywords: Recyclable household waste, Location-allocation, Bins, Inter-municipal collaboration, MILP optimization

I. Introduction

Global municipal solid waste generation exceeded 2.1 billion tons in 2023 and is projected to reach 3.8 billion tons by 2050 [1]. Latin America faces a parallel trajectory with waste volumes expected to grow from 131 million tons in 2005 to 179 million tons by 2030 [2]. This escalating burden poses significant challenges for local authorities with implications for public health, environmental quality, and municipal budgets.

Chile generates approximately 1.15 kg of solid waste per capita daily, substantially above the global average of 0.74 kg [3; 4]. Despite this high generation rate, household recycling remains limited: national averages reach only 13.5%, while Gran Santiago achieves approximately 11.3% [5]. Recent policy initiatives, such as the Extended Producer Responsibility (EPR) Law and the Circular Economy Roadmap, have established frameworks for increasing recycling rates, but municipal implementation remains uneven.

The communes of Cerro Navia (CN) and Quinta Normal (QN) in Santiago's western zone exemplify this gap. In 2022, these communes generated 62,086 and 55,957 tons of municipal waste, respectively, with a combined recycling rate of only 0.9% [6]. Both municipalities operate collection infrastructure yet the adequacy of these facilities for serving residents remains unclear. CN maintains several recycling points for plastics, cardboard, and aluminum [7], while QN has one recycling center, six recycling points, and 15 glass collection sites [8].

This study proposes an inter-municipal collaboration framework for recyclable waste collection between CN and QN. Through joint operations, municipalities can share resources such that residents access a unified network of collection points, reducing infrastructure duplication, and decreasing travel distances [9]. The proposed location-allocation (LA) optimization model identifies optimal bin sites, determines appropriate quantities, and ensures population coverage within acceptable walking distances while respecting bin capacity constraints.

II. Literature Review

The design of collection networks for recyclable household solid waste (RHSW) has attracted sustained attention in operations research. Mixed-integer linear programming (MILP) formulations for LA problems have become the dominant methodological approach, enabling decision-makers to optimize bin locations while balancing cost minimization, coverage maximization, and service accessibility [10]. This review synthesizes relevant methodological contributions, examines evidence on inter-municipal cooperation, and situates the study within the Chilean regulatory context.

A. MILP Location-Allocation Models for Waste Collection

The theoretical foundations of facility location problems trace to [11] on p-median problems and [12] maximal covering formulations. A significant advance involves integrating location and routing decisions: [13] demonstrated 9–17% cost savings by combining MILP bin allocation with metaheuristics for vehicle routing. Subsequent work addressed computational scalability through hierarchical clustering [14].

Chilean applications provide directly relevant precedents. The reference [9] established a two-stage approach for the commune of Renca, achieving USD$254,000 network cost with an average walking distance of 69.1 m and a 100% coverage. The reference [15] extended this framework to address household and recyclable streams separately, while their subsequent work [16] applied a generalized MILP to QN, comparing single-stream versus multi-stream collection. Their results reveal a trade-off: single-stream collection presents lower infrastructure costs, but multi-stream separation yields higher recyclable quality. The latter is a consideration relevant under Chile's EPR Law [17; 18].

B. Inter-Municipal Cooperation in Waste Management

The case for inter-municipal cooperation (IMC) rests on economies of scale in service production and transaction costs for contracting [19]. The meta-analysis confirms that municipalities below 20,000 inhabitants benefit most from cooperation. Empirical studies document cost savings of 5–18% for cooperating municipalities across European contexts [20; 21; 22]. The reference [23] found 13.5% annual savings for Czech municipal associations with benefits accumulating over time as partners optimize shared operations.

C. Chilean Regulatory Context and Research Gap

The Chilean EPR Law mandates producers to recover specified percentages of materials at end-of-life with implementing decrees establishing recycling targets that require infrastructure expansion [17; 18]. For municipalities, these frameworks create both obligations and opportunities through producer responsibility organizations.

Despite the methodological sophistication of MILP models and documented IMC benefits, these research streams have developed largely in parallel. The optimization literature focuses on network design within single jurisdictions, while the IMC literature examines governance without engaging spatial optimization problems. This study bridges this gap by developing a collaborative model that optimizes bin locations across municipal boundaries, quantifying efficiency gains for CN and QN.

III. Case Study

The study area comprises the communes of CN and QN, located in the northwestern sector of Santiago's Metropolitan Region. Both communes share demographic and socioeconomic characteristics, making them suitable candidates for a joint optimization strategy. CN has a population of approximately 142,465 inhabitants distributed across 1,135 census blocks, while QN has 110,026 inhabitants across 743 census blocks. Fig. 1 shows the waste generation points (Census block centroids) and potential candidate public spaces (PS) for locating recyclable bins in CN and QN.

IV. Data Analysis

A. Data Sources

The model requires geospatial, demographic, and operational data integrated through a reproducible Extract-Transform-Load (ETL) pipeline. Table I summarizes the primary data sources employed in this study.

TABLE I
Data sources and their application in the model

Source	Content	Model application
Census 2017 (INE, 2018)	Population per block	Demand parameter h_i
Projections 2022 (INE, 2020)	Intercensal growth	Population adjustment
MDSF-MMA-SUBDERE (2021)	RHSW composition	Mass-to-volume conversion
EPA (2016)	Bulk and semi-compacted density	Mass-to-volume conversion
Ecocontenedores (2025)	Bin capacities and costs	Decision parameters Q_k, c_k
OpenStreetMap / IDE Chile	PS locations, road network	Distance matrices d_{ij}, $e_{j\ell}$

Geospatial layers were processed using QGIS software, generating census block centroids as demand points (C) and candidate PS locations (I) including parks, sport courts, schools, religious buildings, and supermarket esplanades. The matrices with the road network distances between demand points and candidate sites (d_{ij}), and between candidate sites ($e_{j\ell}$) were computed using Python scripts.

B. Composition and Density of Recyclable Fraction in Waste

To quantify RHSW, the normative example included in [24] is adopted. In this study, we assume that a typical municipality (i) estimates its recyclable fraction at 26.8% of total household waste, and (ii) disaggregates that fraction according to the material composition. Additionally, the semi-compacted density is used to represent manual compression or slight settling inside the bin, except for rigid waste, which is not compacted. This practice is recommended in [24] for community bins that do not incorporate a mechanical press. The semi-compacted density is assumed to be twice the value of the specified bulk density. Table II presents the composition shares and the corresponding density values used in this study.

TABLE II
Characterization and density by type of recyclable waste

Waste type	Household Waste (%)	Semi-Compacted Density (kg/L)
Plastic	4.1%	0.029
Cardboard/paper	12.3%	0.085
Glass	8.2%	0.190
Aluminum	2.2%	0.104

C. Demand Calculation

The recyclable waste generation per census block is calculated using the per capita production rate (CPR), block population, and material mass participation within RHSW, as

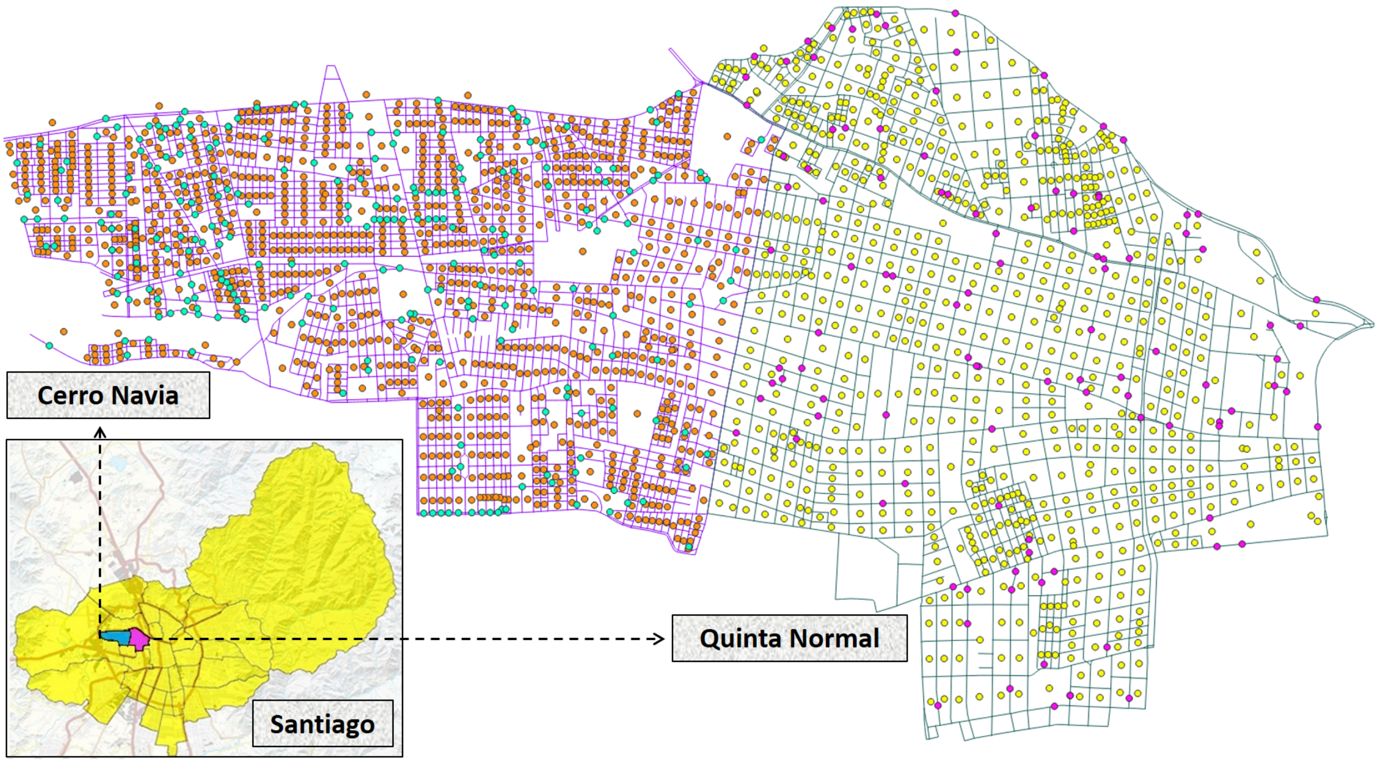

Fig. 1 Waste generation centroids and candidate public spaces in CN and QN.

shown in (1). The mass-to-volume conversion is performed using the bulk density (ρ_L) of each corresponding material:

$$L_{RHSW,t,day} = \frac{CPR \times Population \times Composition_t}{\rho_L^t} \quad (1)$$

where t represents each type of recyclable material (plastic, cardboard, glass, metal). The calculation is repeated for each material, and the total RHSW generation per block for a single-stream strategy is obtained by summing the partial volumes.

D. Bin Type and Cost

The model considers one type of bin with a capacity of 2,200 liters and a unit cost of USD$480.

V. Methodology

A. Mathematical Formulation

The LA problem for recycling bins seeks to determine, in an integrated manner, the collection points and the number of bins to install at each selected point, so that all demand generated by residential blocks is covered within an acceptable walkable radius and does not exceed available capacity. The MILP model proposed by [9] is adopted as a reference.

1) Sets and Indices

C: Set of demand points (census block centroids) indexed by i
I: Set of candidate PS (collection sites) indexed by j, ℓ
K: Set of bin types, indexed by k

2) Parameters

h_i: Volume of RHSW generated at point $i \in C$ [L]
Q_k: Capacity of bin type $k \in K$ [L]
c_k: Unit cost of installing a bin type k [USD]
b_{max}: Maximum number of bins per site
d_{ij}: Distance between generator i and site j [m]
η: Maximum allowed walking distance ($i \to j$) [m]
$e_{j\ell}$: Distance between candidate sites j and ℓ [m]
R_{days}: RHSW collection time horizon (days)
P: Proportion of CPR participation in RHSW assumed by $i \in C$ [%]

3) Decision Variables

$x_j \in \{0, 1\}$: 1 if at least one bin is placed at site j, 0 otherwise
$y_{jk} \in \mathbb{Z}_{\geq 0}$: Number of bins of type k installed at site j
$z_{ij} \in \{0, 1\}$: 1 if point i is assigned to site j, 0 otherwise

4) Model

$$\min_{x,y,z} Z = \sum_{j \in I} \sum_{k \in K} c_k \cdot y_{jk} \tag{2}$$

Subject to:

$$\sum_{j \in I: d_{ij} \leq \eta} z_{ij} = 1 \quad \forall i \in C \tag{3}$$

$$\sum_{i \in C: d_{ij} \leq \eta} h_i \cdot z_{ij} \leq \sum_{k \in K} Q_k \cdot y_{jk} \quad \forall j \in I \tag{4}$$

$$\sum_{k \in K} y_{jk} \leq b_{max} \cdot x_j \quad \forall j \in I \tag{5}$$

$$z_{ij} \geq x_j - \sum_{\ell \in I: \ell \neq j, d_{i\ell} < d_{ij}} x_\ell \quad \forall i \in C, j \in I : d_{ij} \leq \eta \tag{6}$$

Constraint (3) ensures that each census block is assigned to exactly one collection site within the coverage radius η. Constraint (4) ensures that the assigned demand does not exceed installed capacity at each site. Constraint (5) limits the maximum bins per site and ensures coherence with the site opening variable. Constraint (6) forces each block to be assigned to the nearest PS.

B. Experimental Design

Three scenarios are defined for the optimization model:

- Scenario 1 CN: individual planning for CN
- Scenario 2 QN: individual planning for QN
- Scenario 3 CQ: collaborative planning allowing shared PS between both communes

TABLE III
Sensitivity-analysis design

Analysis	Varied parameter	Base case	A	B
Case 1	$b_{\max}$ (bins)	20	22	24
Case 2	P (%)	0.30	0.45	0.65

The sensitivity analysis evaluates two key parameters:

- Case 1 (Maximum number of bins): Variation of maximum number of bins per site (A: 22 bins and B: 24 bins)
- Case 2 (Participation): Variation of citizen participation rate (A: 45% and B: 65%)

The model is implemented in Python using Gurobi 12.0 as the optimization solver, with a time limit of 7,200 seconds and optimality GAP tolerance of 0%.

VI. Results

A. Base Case Scenario

Table IV presents the main results for the base case scenario with parameters: $\eta = 600$ m, user participation = 30%, $b_{max} = 20$, and R_{days} = 3.5 days. The collaborative scenario (CQ) reduces total costs by USD $2,400 (1.2%) compared to the sum of individual solutions. This saving comes from installing less number of bins (404 vs. 409) while maintaining the same number of collection sites (139 PS). Average walking distance drops from 295 m to 281.5 m under collaboration, a 4.6% improvement in service accessibility. Bin utilization increases from 85% to 87.3%, indicating better consolidation of demand across the network.

TABLE IV
Results for the Base Case Scenario

	Total bin costs (USD)	Optimality GAP (%)	Selected PS	Number of installed bins	Avg. Walking distance	Avg. bin utilization (%)
Individual						
CN	99,840	5.77%	79	208	257.9	84.7
QN	96,480	0.00%	60	201	332	85.2
Total	196,320		139	409	294.95	84.95
Collaborative						
CQ	193,920	2.48%	139	404	281.5	87.3
Difference	-2,400		0	-5	-13	2

All scenarios were solved under identical computational settings, ensuring a methodological consistency for a cross-scenario comparison. QN attains proven optimality (GAP = 0%), while CN and CQ retain residual gaps of 5.77% and 2.48%, respectively, reflecting their larger problem sizes (1,135 census blocks for CN and 1,878 combined for CQ). Extended exact runs on the CN instance reveal a sharp plateau in convergence: 40 additional hours of branch-and-bound reduce the gap from 5.77% to 5.25%, indicating that further exact computation yields diminishing returns while the incumbent solution remains stable. Because both individual and collaborative strategies carry residual gaps under the same protocol, the comparison between them is internally consistent, and the operational outputs (i.e., site selection, bin counts, coverage, and utilization) remain robust to the gap magnitude. Future iterations could explore decomposition schemes, matheuristics, or Lagrangian relaxations to tighten convergence on larger instances.

The number of selected PS remains constant at 139 in both approaches, suggesting that collaboration benefits arise from redistributing bins more efficiently rather than from eliminating collection sites. Bins located at the border areas can serve residents from both communes, reducing redundant capacity.

B. Sensitivity Analysis

1) Case 1: Maximum number of bins per site

Increasing b_{max} from 20 to 22 and 24 bins produces no change in any metric. This indicates that the constraint is not active in the current solutions, meaning that no site requires more than 20 bins. The spatial distribution of candidate PS and demand density maintains capacity requirements below this threshold under all tested conditions.

2) Case 2: Participation rate

Tables V and VI present results when the citizen participation increases to 45% and 65%, respectively. These scenarios evaluate how collaboration benefits adapt to varying demand intensities.

At a 45%-citizen participation in Table V, total costs under individual operation reach USD $285,600 with 595 bins distributed across 141 PS. The collaborative scenario reduces costs by USD $1,920, requiring 4 fewer bins and 3 less collection sites. The average walking distance improves by approximately 10 m, and the bin utilization increases from 87.95% to 88.7%, indicating more efficient resource allocation.

At a 65%-citizen participation in Table VI, total individual costs reach USD $402,240 with 838 bins across 154 PS. Under collaboration, costs decrease by USD $1,440 with 3 fewer bins required. Notably, the number of selected PS drops from 154 to 140 with a reduction of 14 sites (9.1%). This result demonstrates that higher demand density enables substantial infrastructure consolidation. The walking distance improves by 5 m, and bin utilization increases to 91.7%. A consistent pattern emerges across participation levels, collaboration delivers benefits in all scenarios, though the nature of these benefits evolves with demand intensity.

At lower participation rates, collaboration primarily generates direct monetary savings through boundary optimization, achieving 1.2% cost reduction at a 30%-citizen participation. As citizen participation increases, the benefits transition toward infrastructure consolidation. At a 65%-citizen participation, collaboration enables a 9.1% reduction in collection sites while maintaining service quality. This consolidation represents significant operational advantages, including reduced maintenance requirements, simplified logistics, and lower administrative overhead—benefits that extend beyond the direct cost metrics captured by the model.

TABLE V
Results for Case 2 - A with 45% Participation

	Total bin costs (USD)	Optimality GAP (%)	Selected PS	Number of installed bins	Avg. Walking distance	Avg. bin utilization (%)
Individual						
CN	$145,920	4.61%	81	304	255.8	88.1
QN	$139,680	0.00%	60	291	334	87.8
Total	285,600		141	595	294.9	87.95
Collaborative						
CQ	$283,680	2.37%	138	591	285.2	88.7
Difference	-1,920		-3	-4	-10	+0.75

These findings suggest that inter-municipal collaboration remains advantageous across the full spectrum of participation scenarios. While the percentage cost savings moderate at higher participation levels, the substantial reduction in required infrastructure (14 fewer sites at a 65%-citizen participation) demonstrates that collaboration benefits scale in different but equally valuable dimensions as demand increases.

TABLE VI
Results for Case 2 - B 65% Participation

	Total bin costs (USD)	Optimality GAP (%)	Selected PS	Number of installed bins	Avg. Walking distance	Avg. bin utilization (%)
Individual						
CN	$207,360	3.94%	95	432	240.9	90
QN	$194,880	0.00%	59	406	335.5	92.3
Total	402,240		154	838	288.2	91.15
Collaborative						
CQ	$400,800	2.04%	140	835	283.2	91.7
Difference	-1,440		-14	-3	-5	+0.55

C. Allocation of Collaborative Savings

The collaborative scenario generates a total saving of USD $2,400 that must be distributed between CN and QN to preserve incentives for joint operation. Cooperative game theory provides several methods for this purpose, including the Shapley value, the nucleolus, the Alternative Cost Avoided Method (ACAM), and the Equal Profit Method (EPM) proposed by [25] specifically to yield as equal relative savings as possible across participants. A recent review by [26] catalogs more than 40 allocation methods applied in collaborative transportation problems and reports that volume-proportional schemes, although intuitive, frequently violate stability conditions in practice.

In the bilateral CN–QN setting, the Shapley value, the nucleolus, and the ACAM converge to the same allocation: each commune retains USD $1,200 of the joint saving, thus, CN and QN incur in a cost of USD $98,640 and USD $95,280, yielding relative savings of 1.20% and 1.24%, respectively. Conversely, the EPM equalizes relative savings by assigning $y_j = c(N) \cdot c(\{j\}) / \sum_{i \in N} c(\{i\})$ in the bilateral case, resulting in USD $98,619 for CN and USD $95,301 for QN, with both communes attaining identical relative savings of 1.22%. A naive volume-proportional allocation based on population shares would instead assign USD $109,417 to CN and USD $84,503 to QN. This distribution suggest that CN would pay an additional cost of USD $9,577 when collaborating than operating alone, violating individual rationality and rendering the coalition unstable. Table VII summarizes these results.

TABLE VII
Cost allocation methods for the base case

Method	CN payment (USD)	QN payment (USD)	CN saving (%)	QN saving (%)
Stand-alone	99,840	96,480	—	—
Shapley / Nucleolus / ACAM	98,640	95,280	1.20	1.24
EPM	98,619	95,301	1.22	1.22
Population-proportional	109,417	84,503	−9.59	12.41

Given the socioeconomic and demographic asymmetries between both communes, the EPM is adopted as the recommended allocation rule. By construction, this method respects differences in stand-alone costs and ensures that neither commune perceives a percentage disadvantage relative to the other—a property that strengthens acceptability in negotiation contexts where the participants face different fiscal capacities and service baselines. The methodological gap between corestable allocations is modest in the bilateral case, as Shapley, the nucleolus, and ACAM collapse to a single point. The full diagnostic value of comparing these methods, together with blocking-power-based solutions such as the modiclus or the SM-nucleolus, emerges as additional communes join the coalition [26].

VII. Conclusions

This study applied a MILP model for solving the LA problem while comparing individual and collaborative bin location strategies for recyclable household waste in the communes CN and QN in the city of Santiago, Chile. The base case shows that collaboration reduces costs by 1.2% (USD $2,400), while improving average walking distance by 4.6% and increasing bin utilization by 2.4%. These gains require no additional investment, as they result purely from the joint optimization of the bin network.

Sensitivity analysis results suggest that the maximum number of bins per site is not a binding constraint under current conditions. On the other hand, in scenarios where participation is expected to increase over the years, collaboration continues to deliver value, with benefits evolving from immediate cost reductions to long-term operational efficiencies (for example, fewer active collection sites result in reduced logistics associated with waste collection operations).

The model solves the LA problem, excluding routing optimization, which captures additional collaboration benefits. Participation rates are assumed to be uniform across blocks, while actual behavior varies spatially.

While this study provides an initial answer to the cost allocation question through the Equal Profit Method in the bilateral CN–QN case, extending the framework to multi-commune coalitions would allow for a richer comparison of allocation methods, where the differences between Shapley, the nucleolus, and blocking-power-based solutions become more diagnostic [26]. Future work could also address multi-stream recycling systems, as the current study only considers single-stream collection. Integrating the LA solution with vehicle routing under the same individual and collaborative scenarios would complete the joint design of the recyclable collection system and capture additional collaboration benefits not visible at the location-allocation level. Finally, computational scalability for larger instances could be addressed through decomposition schemes or matheuristics.

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References

[1] United Nations Environment Programme, "Global waste management outlook 2024: Beyond an age of waste – turning rubbish into a resource," UNEP, Tech. Rep., 2024, primary source for global waste projections: 2.1 billion tonnes (2023) to 3.8 billion tonnes (2050). [Online]. Available: https://www.unep.org/resources/global-waste-management-outlook-2024

[2] A. Rojas, T. Montecino, and R. O'Ryan, "The potential benefits of introducing informal recyclers and organic waste recovery to a current waste management system: A case study from santiago, chile," *Resour.*, vol. 7, no. 1, p. 18, 2018.

[3] S. Kaza, L. Yao, P. Bhada-Tata, and F. Van Woerden, "What a waste 2.0: A global snapshot of solid waste management to 2050," World Bank, Tech. Rep., 2018, source for global average waste generation (0.74 kg/capita/day). [Online]. Available: http://hdl.handle.net/10986/30317

[4] J. Gálvez-Martos, D. Styles, and H. Schoenberger, "Assessment of the current municipal solid waste management system in chile: Challenges and opportunities," *Sustainability*, vol. 13, no. 21, p. 11644, 2021, source for Chile waste generation rate (1.15 kg/capita/day).

[5] Corporación Ciudades, "Reciclaje y residuos en grandes ciudades de chile," Corporación Ciudades, Tech. Rep., 2024, data source: National recycling rate 13.5%, Gran Santiago 11.3%. Uses RETC (2024) data from Ministerio del Medio Ambiente. Cerro Navia: 0% recycling, Quinta Normal: 1% recycling, Quilicura Norte: 32% (highest in Gran Santiago). [Online]. Available: https://corporacionciudades.cl/wp-content/uploads/2024/07/Estudio-reciclaje-2024.pdf

[6] Kyklos, "Estudio de recuperación, reciclaje y valorización comunal," Chile Sin Basura 2040, Tech. Rep., 2021, interactive Power BI database covering 279 municipalities (81% of national total). Elaborated with Todosreciclamos and Asociación Chilena de Municipalidades (AChM). 2022 data: Cerro Navia 62,086 tonnes, Quinta Normal 55,957 tonnes, recycling rate 0.9%. [Online]. Available: https://chilesinbasura.cl/estudio-de-recuperacion-y-valorizacion-comunal/

[7] Municipalidad de Cerro Navia, "Cerro navia en cifras: Infraestructura de reciclaje," 2024, municipal website describing puntos verdes locations for plastics, cardboard, and aluminum collection. [Online]. Available: https://www.cerronavia.cl/cerro-navia-en-cifras/

[8] Biblioteca del Congreso Nacional de Chile, "Reportes estadísticos comunales: Quinta normal," Sistema Integrado de Información Territorial (SIIT), 2020, reports 1 punto limpio, 6 puntos verdes, and 15 glass-only collection points. [Online]. Available: https://www.bcn.cl/siit/reportescomunales/comunas_702.html

[9] C. Blazquez and G. Paredes-Belmar, "Network design for efficient location of bins for curbside recyclable collection in a chilean metropolitan area," *Waste Manage.*, vol. 116, pp. 179–189, 2020.

[10] H. Eiselt and V. Marianov, "Location modeling for municipal solid waste facilities," in *Contributions to Location Analysis: In Honor of Zvi Drezner's 75th Birthday*, H. Eiselt and V. Marianov, Eds. Springer, 2019, pp. 391–422.

[11] S. Hakimi, "Optimum locations of switching centers and the absolute centers and medians of a graph," *Oper. Res.*, vol. 12, no. 3, pp. 450–459, 1964.

[12] R. Church and C. ReVelle, "The maximal covering location problem," *Pap. Reg. Sci. Assoc.*, vol. 32, no. 1, pp. 101–118, 1974.

[13] T. Ramos, M. Gomes, and A. Barbosa-Póvoa, "Planning waste cooking oil collection systems," *Waste Manage.*, vol. 33, no. 8, pp. 1691–1703, 2013.

[14] R. Šomplák, M. Pavlas, J. Kropáč, O. Putna, and V. Procházka, "Logistic model-based tool for policy-making towards sustainable waste management," *Clean Technol. Environ. Policy*, vol. 16, no. 7, pp. 1275–1286, 2014.

[15] D. Rossit, S. Nesmachnow, and J. Toutouh, "Exact and heuristic approaches for multi-objective garbage accumulation points

location in real scenarios," *Waste Manage.*, vol. 105, pp. 467–481, 2020.
[16] D. Rossit, J. Toutouh, and S. Nesmachnow, "A bi-objective integer programming model for locating garbage accumulation points: A case study," *Rev. Fac. Ing.*, vol. 30, no. 55, p. e11617, 2021.
[17] Ministerio del Medio Ambiente de Chile, "Ley 20.920: Marco para la gestión de residuos, la responsabilidad extendida del productor y fomento al reciclaje," Biblioteca del Congreso Nacional de Chile, 2016. [Online]. Available: https://www.bcn.cl/leychile/navegar?idNorma=1090894
[18] ——, "Decreto supremo n° 12: Establece metas de recolección y valorización y otras obligaciones asociadas de envases y embalajes," Biblioteca del Congreso Nacional de Chile, 2021. [Online]. Available: https://www.bcn.cl/leychile/navegar?idNorma=1167293
[19] G. Bel and M. Warner, "Inter-municipal cooperation and costs: Expectations and evidence," *Public Adm.*, vol. 93, no. 3, pp. 714–730, 2015.
[20] G. Bel and M. Mur, "Intermunicipal cooperation, privatization and waste management costs: Evidence from rural municipalities," *Waste Manage.*, vol. 29, no. 10, pp. 2772–2778, 2009.
[21] E. Dijkgraaf and R. Gradus, "Collusion in the dutch waste collection market," *Local Gov. Stud.*, vol. 33, no. 4, pp. 573–588, 2007.
[22] M. Ferraresi, G. Migali, and L. Rizzo, "Does inter-municipal cooperation promote efficiency gains? evidence from italian municipal unions," *J. Reg. Sci.*, vol. 58, no. 5, pp. 1017–1044, 2018.
[23] M. Struk and E. Bakoš, "Factors affecting the performance of municipal solid waste collection: A review article," *Waste Manage. Res*, vol. 40, no. 7, pp. 943–958, 2022.
[24] Sistema Nacional de Inversiones, "Metodología para formulación y evaluación social de proyectos para el manejo o gestión residuos sólidos domiciliarios y asimilables," 2021, economía Circular Chile. [Online]. Available: https://www.subdere.gov.cl/sites/default/files/220818_Metodologia_GIRS_vf.pdf
[25] M. Frisk, M. Göthe-Lundgren, K. Jörnsten, and M. Rönnqvist, "Cost allocation in collaborative forest transportation," *Eur. J. Oper. Res.*, vol. 205, no. 2, pp. 448–458, 2010.
[26] M. Guajardo and M. Rönnqvist, "A review on cost allocation methods in collaborative transportation," *Int. Trans. Oper. Res.*, vol. 23, no. 3, pp. 371–392, 2016.