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Research article

Understanding household recycling behavior in a developing country: Socioeconomic and territorial gaps in Colombia

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ABSTRACT

This study analyzes the determinants of household recycling in Colombia, a middle-income country marked by inequalities in waste management. Using data from the 2023 Quality of Life Survey (ECV), we estimate standard, multilevel, and multivariate probit models to assess the impact of socioeconomic, demographic, and contextual factors on recycling behavior. Results highlight the importance of household income, digital connectivity, service access, and pro-environmental attitudes. A behavior index is constructed to capture latent environmental dispositions. The analysis reveals strong interdependencies among recycling decisions for paper, plastic, and glass, and notable territorial disparities linked to structural barriers. Simulation exercises show that households with more resources and stronger environmental orientations have significantly higher recycling probabilities. These findings offer insights for designing inclusive recycling policies in developing countries, emphasizing the need for behavioral incentives, service provision, and environmental education to enable widespread participation and promote sustainable waste management systems.

1. Introduction

Household recycling has emerged as a cornerstone of sustainable urban solid waste management. Beyond reducing pressure on final disposal systems, it contributes to natural resource conservation and climate change mitigation through the reduction of greenhouse gas emissions (Vicente and Reis, 2008; Viscusi et al., 2023). Over the past decades, academic literature has shown that recycling behavior in households is not driven solely by technical or economic motives but results from the complex interplay of individual (attitudes, values, habits), social (norms, support networks), structural (infrastructure, access to services), and regulatory (public policy, incentives) factors (Aprile and Fiorillo, 2019).

From this perspective, household recycling should be understood as a socially conditioned behavior, influenced by perceived efficacy, pro-environmental values, moral norms, and past experiences (Chan and Bishop, 2013; Islam et al., 2024). However, these motivations are often constrained by logistical barriers, such as inadequate infrastructure, limited space in housing units, or the absence of feedback regarding the final destination of waste (Kurz et al., 2007; Monnot et al., 2014). Therefore, fostering recycling requires not only awareness-raising but also structural changes to the physical and symbolic environments in which daily practices unfold.

This approach is especially relevant in Global South contexts, where formal waste management systems coexist with fragmented and frequently precarious informal networks. In many developing countries, informal recycling accounts for up to 90 % of recovered recyclable materials (Wilson et al., 2006). Yet, waste pickers, key actors in this process, often operate outside formal systems, facing discrimination, unsafe working conditions, and extremely low incomes. Despite this, studies show that integrating waste pickers into municipal systems improves both the efficiency of recycling operations and their quality of life (Dias, 2016).

Colombia offers a paradigmatic case. Although the country has formally adopted a circular economy approach and a National Policy for Integrated Solid Waste Management (PNGIRS), it continues to face major structural challenges: informality, institutional fragmentation, weak coordination between waste separation and material recovery, and stark disparities between urban and rural areas (Departamento Nacional de Planeación - DNP, 2016). These gaps reflect differences in institutional capacity, service coverage, and cultural engagement with recycling, limiting the effectiveness of public policy and exacerbating territorial inequality.

Regionally, Latin America continues to report low urban recycling rates, between 4 % and 10 % of total municipal waste, despite progressive regulatory frameworks (ONU Medio Ambiente, 2018). With an

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average recycling rate of 11 % and significant interdepartmental disparities, Colombia presents a compelling empirical setting to examine the tensions between regulation, informality, and inclusion, while also providing insights for designing replicable policy strategies in other emerging economies.

This article is organized into six sections. Following this introduction, Section 2 reviews theoretical and empirical frameworks on the determinants of household recycling. Section 3 presents the data and methodological approach. Section 4 reports the results of econometric models, while Section 5 discusses the findings considering the literature and Colombia's institutional context. Finally, Section 6 concludes with policy recommendations aimed at strengthening inclusive and territorially sensitive waste governance systems.

2. Theoretical framework

The growing pressure on urban solid waste management systems, driven by population growth, urbanization, and rising consumption, has prompted the design of public policies aimed at promoting recycling as a strategic axis for environmental sustainability and the transition to a circular economy (Gilli et al., 2018; Zeller et al., 2019). However, the effectiveness of these policies largely depends on the active participation of households, which are the primary generators of waste and play a central role in source separation (Vicente and Reis, 2008).

Household recycling behavior has been analyzed from three dominant theoretical perspectives: economic, psychological, and institutional.

2.1. Economic perspective: recycling as a public good

From the standpoint of environmental economics, recycling is conceived as an intergenerational public good with positive externalities. This condition leads to private underinvestment and justifies government intervention (Duggal et al., 1991; Kinnaman, 2006). In this framework, recycling behavior is explained by variables such as income, education, program duration and frequency, and the number of accepted materials. Nevertheless, several studies have questioned the effectiveness of direct monetary incentives, showing their limited impact on actual behavior (Chalak et al., 2016; Ferrara and Missios, 2012). In contrast, the provision of accessible services, especially door-to-door collection, emerges as a key factor in increasing participation and lowering transaction costs.

2.2. Psychological perspective: attitudes, norms, and habits

The psychological approach is rooted in the Theory of Planned Behavior (TPB) and the Theory of Reasoned Action. These frameworks incorporate elements such as attitudes toward behavior, subjective norms, perceived behavioral control, and moral commitment (Ajzen, 1991; Bezzina and Dimech, 2011; Chan and Bishop, 2013). Research by Abbott et al. (2013), Hage et al. (2009), and Wang et al. (2019) highlights the influence of intrinsic motivations such as the "warm-glow," civic duty, and social pressure, often more effective than financial incentives. More recently, Islam et al. (2024) have emphasized the role of habit formation as a powerful predictor of sustainable recycling behavior.

Several studies also point to a persistent gap between intention and actual behavior. This gap is influenced by logistical factors such as the convenience of collection systems, availability of storage space, clarity of recycling schemes, and trust in the process (Oskamp et al., 1991; Owens et al., 2000; Tucker and Speirs, 2003).

2.3. Institutional perspective: state capacity and governance

From an institutional viewpoint, the effectiveness of recycling is also shaped by the structural conditions of governance. The presence of coherent regulatory frameworks, adequate infrastructure, and intergovernmental coordination has a direct impact on household decisions (Henao-Rodríguez et al., 2024; United Nations Human Settlements Programme, 2010). In many developing countries, such as Colombia, the coexistence of informal recycling systems, fragmented governance, and exclusion of waste pickers presents serious challenges (Dias, 2016; Wilson et al., 2006).

Informal recycling, which accounts for up to 90 % of recovered recyclable materials in some Global South cities, plays a functional yet precarious role in circular economies. Its formal integration into municipal systems has been shown to improve both operational efficiency and social equity (Gittins and Letenyei, 2025).

2.4. Integrated approaches and the Colombian case

Recent literature advocates for integrated models that combine individual, contextual, and institutional factors (Barr, 2007; Do Valle et al., 2004). These frameworks are particularly relevant in urban settings in emerging economies, where recycling participation is conditioned by socioeconomic inequalities, infrastructure deficits, and localized social norms.

In Colombia, empirical research remains scarce but is growing. Padilla and Trujillo (2018) found that recycling willingness in Bogotá is positively associated with socioeconomic status, educational attainment, internet access, housing tenure, and participation in environmental organizations. Henao-Rodríguez et al., (2024), using a large-scale machine learning analysis, identified system trust, length of urban residence, local infrastructure, and environmental concern as key determinants of source separation.

These findings underscore the need for differentiated, culturally sensitive, and territorially grounded public policies. They also highlight Colombia as a valuable empirical case for understanding how public policy, social factors, and local capacity interact in the adoption of sustainable practices, and for deriving lessons applicable to other Global South contexts.

3. Materials and methods

3.1. Data source and sample design

This study is based on microdata from the 2023 wave of the National Quality of Life Survey, (ECV), conducted annually by Colombia's National Administrative Department of Statistics (DANE). The ECV employs a complex sampling design, which is probabilistic, stratified, and multistage, ensuring representativeness at the national, regional, departmental, urban-rural, and metropolitan levels. In 2023, the survey was implemented using 356 strata and 8542 primary sampling units, covering a final sample of 86,063 households. These observations represent an expanded population of approximately 17.9 million Colombian households.

The analysis focuses on a subsample of households with complete information regarding waste collection services. Observations with missing or inconsistent data were excluded. The final analytical sample preserves national urban representativeness and includes households from all Colombian departments.

3.1.1. Dependent variable

The main outcome variable is a binary indicator of household recycling behavior, coded 1 if the household reports separating solid waste at the source, and 0 otherwise. This variable serves as a proxy for household recycling participation and is used as the dependent variable in all estimated models.

An additional classification distinguishes between formal and informal waste collection schemes based on DANE's operational definition. A household is considered to have formal collection coverage when waste is collected, either regularly or occasionally, by legally constituted public, private, or communal entities. Conversely, if collection is performed by informal recyclers (e.g., individuals using carts without affiliation), the household is considered not covered by a formal service. This distinction allows identification of institutional barriers affecting recycling behavior.

3.1.2. Independent variables

Independent variables are structured across three analytical levels.

- **Individual level**: Age and gender of the household head, and the educational attainment of the most educated household member.
- **Household level**: Household size, proportion of elderly members, housing tenure (owned, rented, or informal), dwelling type (house, apartment, other), household income (log-transformed), poverty status, and a pro-environmental behavior index.
- **Contextual level**: Area of residence (urban/rural), department, access to public utilities (water, electricity, sewerage), internet connectivity, perceived environmental quality, type of waste disposal, and coverage of formal collection services.

A quadratic term for the logarithm of income was included in the models to account for the observed non-linear (U-shaped) relationship between income and recycling propensity.

3.2. Construction of the pro-environmental behavior index

To capture household environmental disposition beyond a single action, a latent pro-environmental behavior index was constructed using exploratory factor analysis. The index is based on eight self-reported environmental practices, including water and energy saving, reuse, and sustainable domestic habits. The Kaiser-Meyer-Olkin test (>0.70) and Bartlett's sphericity test confirmed the adequacy of the factor structure. Two principal factors were extracted using the Kaiser criterion (eigenvalue >1) and rotated using the varimax method. Factor scores were standardized and categorized into three ordinal levels: low, medium, and high. This approach is consistent with prior studies modeling latent environmental attitudes and behaviors (Aprile and Fiorillo, 2019; Do Valle et al., 2004).

3.3. Econometric strategy

To account for different aspects of recycling behavior, three complementary econometric models were estimated.

3.3.1. Standard probit model

A basic probit regression estimates the probability that a household recycles, conditional on individual, household, and contextual covariates:

$$P(y_i = 1|X_i) = \Phi(X_i'\beta) \tag{1}$$

Where y_i is the binary recycling indicator, X_i the vector of predictors, β the vector of coefficients, and $\Phi(\cdot)$ the cumulative distribution function of a standard normal distribution.

3.3.2. Multilevel probit model

Given the hierarchical structure of the data (households nested within departments), a multilevel probit model was estimated with random intercepts at the departmental level:

$$P\left(y_{ij} = 1|X_{ij}, u_j\right) = \Phi\left(X_{ij}'\beta + u_j\right), u_j \sim N(0, \sigma^2 u) \tag{2}$$

In this specification, y_{ij} denotes the binary outcome for individual i nested within group j; X_{ij} is the vector of explanatory variables that capture characteristics at both the individual and contextual levels; β represents the vector of fixed effects; and u_j is the random intercept for group j, accounting for unobserved heterogeneity across groups. The hierarchical structure of the model is formulated according to the notation and framework proposed by Simonoff et al., (2013) et al. (2013) and Goldstein (2010).

This specification captures unobserved territorial heterogeneity. The hierarchical formulation is given by.

- ***Level 1 (household):***

$$Y_{im}^{*} = X_{im}'\beta + u_m + \varepsilon_{im}, \varepsilon_{im} \sim N(0, 1) \tag{2.1}$$

Where Y_{im}^{*} represents the latent propensity of household i to recycle material m; X_{im} is the vector of individual-level covariates; u_m denotes the group-level random effect (i.e., the deviation of group j from the overall mean); and ε_{im} is the individual error term, allowing for correlation across recycling decisions.

- *Level 2 (department):*

$$u_j = Z_j'\gamma + \eta_j, \eta_j \sim N\left(0, \tau^2\right) \tag{2.2}$$

Where Z_j represents the vector of explanatory variables at the departmental level, and η_j is the random component not explained by Z_j.

3.3.3. Multivariate probit model

To model joint recycling decisions across materials: paper/cardboard, plastic, and glass, a multivariate probit model was estimated:

$$y_{im}^{*} = X_i\beta_m + \varepsilon_{im}, \varepsilon_i \sim N_M\left(0, \sum\right), m = 1, \ldots, M \tag{3}$$

Where Σ is the variance-covariance matrix that captures the interdependence among recycling decisions. For example, a household with a high propensity to recycle paper may also have an increased likelihood, beyond what is explained by observed variables, of recycling other materials such as plastic or glass. Joint estimation allows for the identification of these patterns, improves statistical efficiency, and provides a more realistic analysis of household environmental behavior.

This model allows estimation of.

i. Marginal probabilities $\Pr(y_m = 1)$: probability of recycling each material independently.
i. Joint success probability $\Pr\left(y_{glass} = 1, y_{paper/cardboard} = 1, y_{plastic} = 1\right)$: proxy for complete recycling behavior.
ii. Joint failure probability $\Pr\left(y_{glass} = 0,\ y_{paper/cardboard} = 0,\ y_{plastic} = 0\right)$: proxy for full exclusion from recycling practices.

This approach enables identification of consistent versus fragmented recycling patterns and the detection of vulnerable household profiles with structural or informational barriers to recycling.

4. Results

The empirical evidence derived from the econometric analysis of the 2023 Colombian Quality of Life Survey (ECV) reveals structural, attitudinal, and contextual determinants influencing household recycling decisions. Standard probit, multivariate probit, and multilevel probit models were applied, along with simulations estimating recycling probabilities under different socio-environmental household profiles.

4.1. Descriptive statistics

Recycling behavior in Colombia shows considerable regional and contextual variability. Across the country, 52.3 % of households report engaging in source separation of at least one recyclable material. A cross-tabulation by waste disposal method and department reveals a strong association between formal service use and recycling practices. Households using official waste collection services exhibit the highest recycling rates (56 %), while only 6 % of those who dump waste into rivers or streams recycle, highlighting the environmental risk of informal waste practices (see Table 1).

At the territorial level, departments such as Bogotá (75.7 %), Cundinamarca (66.1 %), Boyacá (65.9 %), and Santander (67.3 %) report the highest rates of household recycling. These patterns appear correlated with higher infrastructure coverage and the existence of structured environmental collection schemes. In contrast, Chocó (5.1 %), Vaupés (7.9 %), and Vichada (0.4 %) display critically low rates, suggesting structural barriers and limited institutional engagement.

In addition, households were categorized according to their environmental attitudes using a composite index. The index distribution reveals that 36.8 % of households exhibit high pro-environmental behavior, 33.5 % moderate, and 29.7 % low levels, indicating a relatively even spread of attitudes across the population (see Table 2).

4.2. Standard probit model: average marginal effects

Table 3 reports the estimated average marginal effects from the probit model, which captures the probability of household recycling as a function of selected explanatory variables.

Household location in rural areas increases the probability of recycling by 6.8 percentage points (pp). Waste disposal practices are particularly influential: households that dispose of waste in rivers or open lots show significant reductions in recycling likelihood (−28.4 pp and −9.0 pp respectively), whereas those who burn or bury waste report increased probabilities (+10.8 pp and +13.3 pp respectively), likely due to rudimentary sorting behaviors.

Pro-environmental attitudes strongly predict recycling. Households with medium and high levels of environmental commitment have 10.4 pp and 9.4 pp higher probabilities of recycling than those with low commitment. Internet access increases the likelihood of recycling by 10.4 pp, underscoring the role of digital connectivity in facilitating environmental engagement.

Unexpectedly, years of education exert a slight but negative effect (−0.6 pp), contrary to conventional findings. This may be attributed to multicollinearity with income or geographic access. Income follows a U-shaped pattern: middle-income households recycle less than those at the lower or upper ends of the distribution. Moreover, being below the poverty line reduces the recycling probability by 7.5 pp.

4.3. Multivariate probit model: joint decisions by material type

The multivariate probit model simultaneously analyzes the

Table 2
Distribution of households by level of pro-environmental behavior index.

Pro-Environmental Behavior Index	Freq.	Percent	Cum.
Low	5.327.008	29.74	29.74
Medium	5.996.560	33.48	63.22
High	6.587.675	36.78	100.00
Total	17.911.243	100.00	

Source: Author's elaboration based on ECV 2023 (DANE).

Table 1
Distribution of household recycling by department and waste disposal method.

Department	Waste disposal method (%)						
	Official	River/stream	Lot/ditch	Burned	Buried	Informal	Total
Antioquia	60.3	14.1	21	28.2	44.8	35.3	57.7
Atlántico	42.8	0	5.3	7.8	4.9	20.3	41
Bogotá	75.7		96	53.8	43.3	97.3	75.7
Bolívar	30.4	0	2.6	8	11.3	16.2	24.3
Boyacá	70.4		38.5	54.9	66.7	96.6	65.9
Caldas	54.3		72.9	60.8	41.1	56.6	54.6
Caquetá	23.7	4.0	65.3	56.8	53.4	10.7	31.5
Cauca	61.5	47.5	43.7	82.6	75.1	76.2	69.1
Cesar	22.8	21.8	25.1	12.2	27.9	2.9	21
Córdoba	12.8	0	3.1	5.7	24.5	22.7	10.1
Cundinamarca	68	54.6	52.6	49.4	64.1	72.4	66.1
Chocó	2.9	1	0.4	17.9	11.1	28.1	5.1
Huila	48.2	31.3	18.9	65.9	51.1	47.8	53
La Guajira	10.2	0	3.9	1.6	1.7	18.3	6.4
Magdalena	33.5	0	3.1	5.9	3.2	22.2	26.8
Meta	52	0	41.7	49.9	64.5	53.7	51.9
Nariño	53.2	5.3	35.5	59	36.6	52.6	51.3
Norte Santander	34.8	0	36.9	37	30.4	11.9	35
Quindío	58	100	39.9	44.9	47.1	58.1	57.6
Risaralda	49.9	0	23.6	42	68.4	47	49.3
Santander	68.5	13.1	65.8	64	74.9	32.8	67.3
Sucre	9.9	0	3	2.3	5.9	0	7
Tolima	38	77.4	40.8	48.2	54.5	70.6	40.5
Valle del Cauca	59.3	7.4	22.7	66.2	71.2	68.1	59.2
Arauca	32.0	0.0	8.2	10	16	34.8	24.8
Casanare	54.2	0.0	48	63.1	72.3	67.6	56.2
Putumayo	48.7	0.0	56.8	73.3	27.2	16.7	55.6
San Andrés	0.4	0.0		0.0		0.0	0.4
Amazonas	11.2	0.0	6.9	25.5	35.9	56.2	17.5
Guainía	36.1	0.0	2.8	5.4	9.6	31.8	17.3
Guaviare	23.3	0.0	30.6	37.1	29.4	41.6	27.2
Vaupés	12.2	0.0	0.0	7.3	2.6	0.0	7.9
Vichada	1.6	0.0	0.0	0.0	0.0	8.7	0.4
Total Nacional	55.5	5.8	20.9	40.4	41.9	36.5	52.3

Note: Each cell shows the percentage of households in the department who report recycling and using the specified waste disposal method. The "Total" column indicates the overall percentage of households in the department who report recycling, regardless of disposal method. Because some households use multiple waste disposal practices, percentages within each row may not sum to 100 %. Data are weighted to represent the national distribution of households.
Source: Author's elaboration based on ECV 2023 (DANE).

Table 3
Average marginal effects from the standard probit model.

Dependent variable: Recycle	dy/dx	std. errs.	P > t	[95 %conf. interval]	
Area: Urban					
Rural	0.068	0.013	0.000	0.041	0.094
Waste Disposal Method: Official					
Throw into river/stream	−0.284	0.038	0.000	−0.359	−0.210
Throw into lots/ditch	−0.090	0.027	0.001	−0.142	−0.037
Burn	0.108	0.014	0.000	0.081	0.134
Bury	0.133	0.018	0.000	0.098	0.167
Informal Service	0.004	0.034	0.912	−0.063	0.071
Waste Collection Frequency	0.004	0.005	0.402	−0.005	0.013
Pro-Environmental Behavior: Low					
Medium	0.104	0.009	0.000	0.086	0.121
High	0.094	0.009	0.000	0.076	0.112
Environmental Quality	−0.030	0.026	0.250	−0.081	0.021
Access to Services: None					
One Service	0.085	0.032	0.007	0.023	0.148
Two Services	0.179	0.033	0.000	0.115	0.242
All Services	0.313	0.037	0.000	0.240	0.385
Internet Access	0.104	0.008	0.000	0.088	0.120
Housing Type: House					
Apartment	0.057	0.010	0.000	0.037	0.077
Other	−0.059	0.025	0.018	−0.108	−0.010
Own Home	−0.002	0.008	0.844	−0.017	0.014
Household Size	−0.008	0.002	0.002	−0.012	−0.003
Proportion of Older Adults	0.024	0.007	0.000	0.011	0.037
Sex of Head of Household	0.028	0.007	0.000	0.015	0.041
Age of Head of Household	0.002	0.000	0.000	0.001	0.002
Maximum Years of Education	−0.006	0.001	0.000	−0.008	−0.004
Income Ln	−0.082	0.005	0.000	−0.092	−0.072
Income Ln^2	0.005	0.000	0.000	0.005	0.006
Poor	−0.075	0.010	0.000	−0.094	−0.055

Source: Author's elaboration based on ECV 2023 (DANE).

probability of recycling glass, paper/cardboard, and plastic, while accounting for unobserved correlations across these behaviors (see Table 4).

The results indicate that the same structural and attitudinal variables influence recycling behavior across materials. Rural households consistently show a higher propensity to recycle all materials. Pro-environmental behavior remains a strong predictor, while dumping waste into rivers/lots consistently reduces recycling likelihood. Positive effects are found for Internet access and access to basic services, reaffirming the role of material and informational infrastructure.

The strong correlations between recycling paper and plastic ($\rho = 0.929$), and between glass and both materials, suggest complementary household behaviors. These interdependencies support the case for integrated recycling policies rather than isolated material-focused interventions (see Table 5).

4.4. *Multilevel* ***probit model: territorial heterogeneity***

To account for unobserved contextual factors, the multilevel probit model introduces random intercepts at the departmental level. This specification captures variation in recycling propensity that cannot be explained by individual or household characteristics alone.

Fig. 1 graphically illustrates these departmental effects, with positive deviations in central and Andean departments, and negative deviations concentrated in peripheral regions such as the Amazon, Pacific coast, and Caribbean. This spatial pattern reflects not only differences in infrastructure and service coverage but also broader institutional disparities in environmental governance.

The intraclass correlation coefficient (ICC) is estimated at 13.9 %, indicating that a substantial portion of the variance in household recycling behavior is attributable to contextual differences across departments. Even after adjusting for individual-level covariates, departments such as Bogotá, Boyacá, and Cundinamarca exhibit

Table 4
Estimated coefficients from multivariate probit model by material type.

Dependent variable: Recycles	Glass (β – se)	Paper/cardboard (β -se)	Plastic (β - se)
Area: Urban			
Rural	0.288 (0.014)	0.275 (0.014)	0.296 (0.015)
Waste disposal method: Official			
Throw into river/ stream	−0.768 (0.106)	−0.932 (0.117)	−0.899 (0.136)
Throw into lots/ditch	−0.207 (0.034)	−0.223 (0.033)	−0.152 (0.035)
Burn	0.108 (0.017)	0.157 (0.017)	0.122 (0.017)
Bury	0.142 (0.030)	0.161 (0.029)	0.181 (0.031)
Informal Service	0.266 (0.039)	0.224 (0.040)	0.273 (0.041)
Waste Collection Frequency	−0.008 (0.006)	0.012 (0.006)	0.033 (0.006)
Pro-Environmental Behavior: Low			
Medium	0.270 (0.012)	0.301 (0.012)	0.364 (0.012)
High	0.308 (0.012)	0.309 (0.011)	0.383 (0.012)
Environmental Quality	−0.536 (0.033)	−0.628 (0.031)	−0.536 (0.032)
Access to Services: None			
One Service	0.199 (0.042)	0.115 (0.040)	0.085 (0.042)
Two Services	0.428 (0.042)	0.323 (0.040)	0.268 (0.042)
All Services	0.709 (0.044)	0.643 (0.042)	0.573 (0.044)
Internet Access	0.255 (0.010)	0.304 (0.010)	0.300 (0.010)
Housing Type: House			
Apartment	0.076 (0.013)	0.074 (0.013)	0.087 (0.013)
Other	−0.383 (0.032)	−0.420 (0.031)	−0.395 (0.034)
Own Home	0.012 (0.010)	0.001 (0.010)	0.002 (0.010)
Household Size	−0.020 (0.003)	−0.020 (0.003)	−0.006 (0.003)
Proportion of Older Adults	0.126 (0.008)	0.144 (0.008)	0.146 (0.008)
Sex of head of household: Male			
Women	0.046 (0.010)	0.060 (0.009)	0.066 (0.010)
Years of education	−0.003 (0.001)	−0.006 (0.001)	−0.007 (0.001)
Income Ln	−0.133 (0.007)	−0.108 (0.007)	−0.115 (0.007)
Income Ln^2	0.009 (0.000)	0.007 (0.000)	0.008 (0.000)
Poor	−0.162 (0.016)	−0.190 (0.015)	−0.183 (0.016)
Constant	−1.670 (0.060)	−1.394 (0.057)	−1.495 (0.059)

Source: Author's elaboration based on ECV 2023 (DANE).

Table 5
Estimated correlations between recycling decisions by material type.

Parameter	Coefficient (se)	p-value
ρ21 (Glass – Paper)	0.819 (0.002)	0.000
ρ31 (Glass – Plastic)	0.791 (0.003)	0.000
ρ32 (Paper – Plastic)	0.929 (0.001)	0.000

Source: Author's elaboration based on ECV 2023 (DANE).

significantly higher baseline propensities to recycle. In contrast, departments like Vichada, Sucre, Chocó, and San Andrés fall well below the national average, suggesting the persistence of structural and institutional barriers.

As shown in Table 6 attitudinal and infrastructural factors continue to play a key role in shaping recycling behavior. Access to the internet increases the probability of recycling by 7.7 percentage points, while medium and high levels of pro-environmental behavior raise it by 8.3 and 9.6 points, respectively. More frequent waste collection is associated with a modest but statistically significant increase of 1.3 points.

By contrast, poverty significantly constrains recycling participation, reducing the probability by 3.7 percentage points. These findings reinforce the importance of addressing structural inequality and service access as critical preconditions for promoting sustainable practices among vulnerable populations.

4.5. *Simulated scenarios: socio-environmental household profiles*

Simulations were performed for household archetypes based on key explanatory dimensions: poverty status, environmental attitudes, digital access, and urban/rural location (see Table 7).

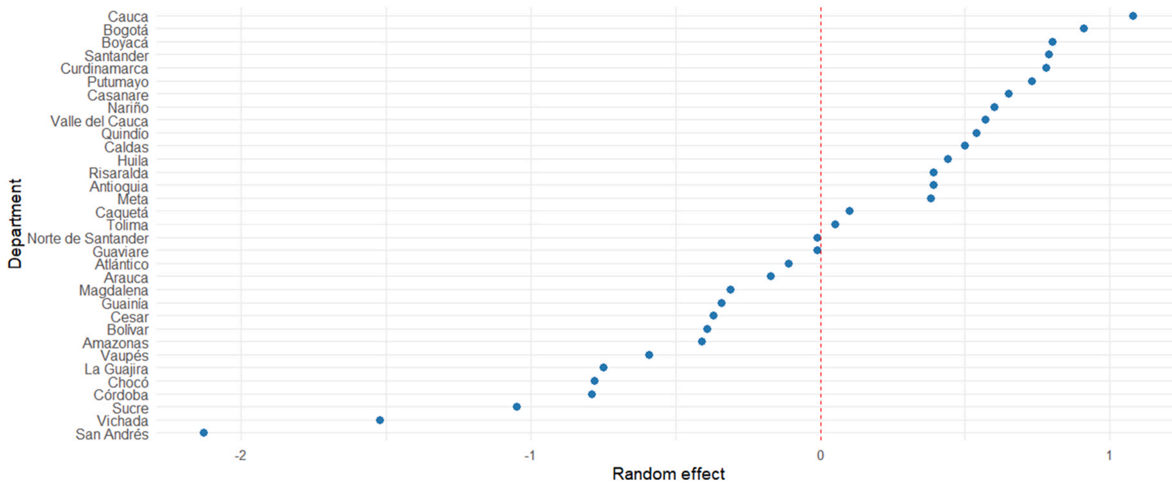

Fig. 1. Department-level variation in recycling propensity: estimated random effects.
Source: Author's calculations.

Table 6
Average marginal effects from the multilevel probit model.

Dependent variable: Recycles	dy/dx	std. errs.	P > t	[95 %conf. interval]	
Area: Urban					
Rural	0.010	0.016	0.517	−0.021	0.041
Waste Disposal Method: official					
Throw into a river/stream	−0.195	0.034	0.000	−0.261	−0.128
Throw into a lot/ditch	−0.041	0.020	0.044	−0.081	−0.001
Burn	0.056	0.023	0.017	0.010	0.102
Bury	0.056	0.023	0.015	0.011	0.101
Informal Service	0.061	0.022	0.005	0.019	0.103
Waste Collection Frequency	0.013	0.006	0.038	0.001	0.025
Pro-Environmental Behavior: Low					
Medium	0.083	0.013	0.000	0.058	0.108
High	0.096	0.015	0.000	0.067	0.125
Environmental Quality	−0.145	0.041	0.000	−0.225	−0.066
Access to Services: None					
One	−0.036	0.027	0.177	−0.088	0.016
Two	−0.024	0.036	0.496	−0.095	0.046
All	0.008	0.035	0.828	−0.061	0.076
Internet Access	0.077	0.011	0.000	0.054	0.099
Housing Type: House					
Apartment	0.013	0.012	0.288	−0.011	0.036
Other	−0.095	0.018	0.000	−0.130	−0.060
Own Home	0.010	0.007	0.159	−0.004	0.024
Household Size	0.008	0.002	0.001	0.003	0.012
Proportion of Older Adults	0.013	0.004	0.004	0.004	0.021
Sex of Head of Household	0.018	0.005	0.000	0.009	0.027
Age of Head of Household	0.001	0.000	0.000	0.001	0.002
Maximum Years of Education	−0.002	0.001	0.000	−0.003	−0.001
Income Ln	−0.033	0.007	0.000	−0.046	−0.020
Income Ln2	0.002	0.000	0.000	0.002	0.003
Poor	−0.037	0.007	0.000	−0.051	−0.024

Source: Author's elaboration based on ECV 2023 (DANE).

Table 7
Simulated recycling probabilities by household profile and material type.

Household Profile	N	Marginal Probabilities			Joint Probability	
		Glass	Paper	Plastic	All = 1	All = 0
Favorable urban	10,145	0.314	0.450	0.475	0.262	0.454
Favorable rural	5351	0.328	0.458	0.487	0.274	0.442
Urban environment	28,767	0.221	0.335	0.344	0.176	0.586
Rural environment	27,010	0.204	0.308	0.319	0.160	0.614
Unfavorable urban	1966	0.070	0.120	0.120	0.046	0.838
Unfavorable rural	6044	0.073	0.127	0.131	0.050	0.828
Other	6780	0.166	0.258	0.282	0.126	0.662
Total	86,063	0.215	0.322	0.335	0.171	0.599

Source: Author's elaboration based on ECV 2023 (DANE).

Table 8
Simulated recycling probabilities by stylized household profiles.

Scenario	Key Conditions	Estimated Probability	Standard Error
Favorable Urban Household	High pro-environmental attitude, internet access, homeownership, 11 years of education, not poor, frequent collection	0.426	0.040
Intermediate Urban Household	Medium pro-environmental attitude, no internet, homeownership, 7 years of education, not poor, moderate collection	0.336	0.035
Vulnerable Rural Household	Low pro-environmental attitude, no internet, no homeownership, 5 years of education, poor, infrequent collection	0.186	0.030

Source: Author's calculations.

Favorable households, non-poor, pro-environmental, connected, achieve the highest joint recycling probabilities (up to 27.4 %). Notably, favorable rural households slightly outperform their urban counterparts, indicating that material conditions, rather than location alone, drive behavior. Middle-income households with limited infrastructure and weak attitudes show lower engagement. Disadvantaged households, especially in rural areas, recycle at the lowest rates, with over 80 % reporting no recycling activity (see Table 8).

5. Discussion

The findings of this study confirm that recycling behavior in Colombian households is shaped by an interplay of structural enablers, personal attitudes, and territorial contexts. The evidence aligns with the Theory of Planned Behavior (Ajzen, 1991), which posits that both behavioral intentions and perceived control are central to decision-making.

Infrastructure access emerges as a decisive enabler. Public services, digital connectivity, and waste collection frequency enhance recycling outcomes, supporting previous studies emphasizing the material conditions necessary for environmental engagement (Ferrara and Missios, 2012). Households lacking these basic conditions are structurally excluded from sustainable practices, regardless of attitudes or education.

Pro-environmental behavior is a robust predictor across all models and materials. This reinforces the role of internalized norms and social values in driving sustainable behavior, echoing Chan and Bishop (2013) and Jekria and Daud (2016). Unexpectedly, education does not positively affect recycling in this context. This deviation from global findings may be explained by contextual factors: formal education in Colombia may not include environmental literacy or practical applications, limiting its influence.

The U-shaped relationship between income and recycling aligns with theories of segmented environmental behavior. Low-income households may recycle out of necessity or economic utility, while high-income households may do so out of conviction and access. Middle-income households often lack both incentives, infrastructure, and normative pressure to recycle (Kinnaman, 2006; Medina, 2008).

The multilevel results underscore the importance of territorial context. Departments differ in their baseline recycling rates due to unobserved political, institutional, or infrastructural conditions. Hence, policies must be territorially differentiated. Departments such as Vichada or Chocó require tailored interventions to overcome systemic exclusion.

Finally, simulations provide practical insight for policy design. They illustrate the cumulative effect of digital access, attitudes, income, and territorial context. Profiles combining favorable structural and attitudinal traits are far more likely to recycle. These findings advocate for multidimensional and targeted interventions, addressing not just awareness, but also service delivery, digital inclusion, and material capabilities, to enable broad participation in recycling and accelerate the transition to a circular economy.

6. Conclusions

Household recycling in Colombia constitutes a complex practice shaped by the interaction of structural, attitudinal, and socioeconomic factors. Access to public services, digital connectivity, housing type, income level, and poverty status intersect with pro-environmental attitudes to determine the likelihood of household participation. This multidimensionality results in a pronounced social and territorial stratification of recycling behaviors, with significant disparities across regions and household profiles.

The results show that departments with lower levels of recycling are those most affected by structural poverty and deficient infrastructure. This territorial inequality underscores the urgency of adopting context-sensitive public policies that integrate investments in basic infrastructure, environmental literacy, and logistics schemes tailored to local conditions. In line with previous studies (Padilla and Trujillo, 2018), such a territorial approach enables a more efficient and equitable allocation of public resources.

Pro-environmental attitudes play a fundamental role as catalysts of recycling behavior, but they do not operate in isolation. Their effect is either enhanced or constrained by the availability of enabling material conditions. This finding reinforces the need for policies that combine the promotion of environmental values with the provision of practical means for action. In this regard, the complementarity between attitudinal and structural factors emerges as a guiding principle for the design of effective interventions.

Environmental inclusion gaps remain critical among vulnerable households, those experiencing poverty, lacking access to basic services, or disconnected from digital networks. These households face environmental exclusion that not only limits their participation but also reinforces broader social inequalities. Therefore, they must be prioritized in public strategies through targeted service subsidies, community capacity building, and the integration of informal recyclers into formal systems. Environmental justice must be explicitly recognized as a core dimension of waste governance, aligned with the principles of territorial equity and inclusive sustainability.

Moreover, recycling behaviors do not develop in isolation. The high correlation observed among decisions to recycle different materials suggests the existence of integrated behavioral patterns, likely mediated by social norms, shared habits, or common institutional arrangements. This finding supports the need for analytical and policy approaches that promote holistic and multi-material recycling practices.

Ultimately, the most effective public policies in this field are those that integrate three key dimensions: accessible infrastructure, appropriate incentives, and cultural transformation. It is not enough to expand service coverage or enact regulations; it is essential to create conditions that enable and motivate environmental action at the household level. This integrated vision is consistent with transformative and systemic approaches that call for structural change in consumption and waste disposal patterns (Bezzina and Dimech, 2011; Schoeman and Rampedi, 2022), in accordance with the principles of the circular economy.

7. Policy implications and future research

The findings of this study underscore the urgent need for differentiated and inclusive policy approaches that address the persistent socioeconomic and territorial disparities in household recycling participation. Local governments must prioritize investments in waste management infrastructure, especially in underserved urban peripheries and rural areas, where institutional and logistical barriers remain entrenched. Strengthening environmental education campaigns and designing targeted incentives for vulnerable households, particularly those lacking digital access or basic services, can foster more equitable engagement.

Given the strong interdependence among recycling behaviors across materials, integrated collection systems and community-based participation schemes should be expanded to increase coverage and effectiveness. In the context of developing countries with widespread informal recycling, such as Colombia, policy frameworks must also focus on the formal inclusion of waste pickers, whose contribution remains indispensable but often unrecognized. Incorporating these actors into municipal systems improves not only efficiency but also social equity and labor conditions.

Future research should explore longitudinal dynamics of recycling behavior, investigate causal pathways between structural factors and environmental action, and assess the effectiveness of behavioral interventions in informal and low-capacity settings. Such insights are essential to design circular economy strategies that are not only technically viable but also socially just.

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.

Data availability

Data will be made available on request.

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