Factors Influencing Environmental Awareness and Solid Waste Management Practices in Bogotá: An Analysis Using Machine Learning

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Factors Influencing Environmental Awareness and Solid Waste Management Practices in Bogotá: An Analysis Using Machine Learning

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ABSTRACT: The effective management of solid waste presents a pressing challenge within the environmental sector, given its adverse impacts on health and the environment (water, soil, air). This global concern is particularly relevant for cities striving to implement efficient waste management strategies. This study explores the factors that impact environmental awareness and solid waste management practices in Bogota, offering valuable insights for designing and implementing effective public policies and environmental management strategies. By understanding the drivers of environmental behavior among city residents, local authorities can devise more precise interventions and implement environmental education and awareness programs aimed at fostering sustainable waste management practices. The city of Bogota faces unique challenges in waste management, considering that the amount of waste generated per capita has increased fivefold in recent years, coupled with being a densely populated city. Data from the 2021 Environmental Culture Survey conducted by Bogota's Mayor's Office, consisting of 266,994 entries, was analyzed using LASSO regularized logistic regression. LASSO offers advantages such as automatic feature selection, multicollinearity reduction, regularization to prevent overfitting, computational efficiency, and flexibility in a variety of modeling problems. The study provides significant insights into waste separation behaviors in Bogota, Colombia. The algorithm, with a 70% accuracy coefficient, indicates a direct correlation with the number of years individuals have resided in the city, demonstrating a 3.2% increase in the probability of consistently separating waste. Residents of Usaquén, Chapinero, Barrios Unidos, Bosa, and Teusaquillo exhibit higher probabilities of consistent waste separation, while those in San Cristóbal, Usme, Suba, Antonio Nariño, Rafael Uribe Uribe, and Ciudad Bolívar tend to have lower probabilities. Confidence in the recycling process significantly impacts behavior, with a 62.7% increase in the probability of consistently separating waste among those assured of the process. The study also highlights the importance of recycling bin availability, as individuals with only one bin in the kitchen show an 81.2% likelihood of almost never separating waste. The discoveries from this study regarding the factors influencing household waste separation and recycling practices offer valuable insights for enhancing environmental education and promotion strategies. By delving into the intricate dynamics of sociodemographic, geographical, and attitudinal elements, this research sheds light on the complexities of waste separation behaviors. These insights are pivotal for crafting tailored policies that can yield greater effectiveness in promoting sustainable practices and facilitating environmental conservation.

KEYWORDS: Bogotá, environmental culture, environmental awareness, LASSO, machine learning, waste

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Introduction

Solid waste management presents a significant environmental challenge in contemporary society. The proliferation of waste generation, coupled with inadequate disposal methods, can have detrimental effects on public health and the environment, including water, soil, and air (Gu et al., 2024; Kannankai & Devipriya, 2024; Seif et al., 2024; Sharma et al., 2024). Despite regulations aimed at mitigating their impact, waste generates leachate during decomposition, which contaminates soil and water resources, threatening life. It is important to note that these leachates contain various types of contaminants that can persist in the environment, enter the food chain, and affect both the ecosystem and human health (Iravanian & Ravari, 2020).

In addition to the aforementioned, the lack of waste classification has adverse effects on water and air quality. There are various types of contaminants, such as inorganic ones including heavy metals (mercury, lead, and cadmium), and biological contaminants (Siddiqua et al., 2022). In water, heavy metals once released can accumulate in sediments and aquatic organisms, affecting the food chain. In the air, these metals can be released through industrial processes, fossil fuel combustion, and mining activities. Once in the air, they can disperse and be transported over long distances before being deposited in the soil or bodies of water through atmospheric deposition, such as acid rain. Inhalation of vapors or particles of these metals can cause respiratory problems and damage to the central nervous system, among other adverse effects on human health and the environment (Zhang et al., 2022).

Batista et al. (2021) highlight the urgent need for a deeper analysis of sustainable and integrated solid waste management in municipalities of developing countries. These nations still lack adequate procedures to address society's needs, particularly regarding urban solid waste management. Factors such as inequality, urbanization, and economic growth, along with socio-economic, cultural, and political aspects, further

Figure 1. Examples of waste management in Bogota.

complicate this management in developing countries. Therefore, studies are needed to contribute to more comprehensive diagnostics so that actions and policies can be tailored to municipal realities.

In this regard, Awino and Apitz (2024) emphasize that successful implementation of solid waste management requires broad stakeholder participation and integrated planning and infrastructure. They stress the crucial importance of public and personal perceptions, attitudes, and behaviors in informed decisions about solid waste management. However, the lack of formal and informal stakeholder integration, incorrect institutional information, and limited recycling programs hinder the development of sustainable solid waste management systems, especially in regions of the Global South.

The research gap this study aims to fill is the absence of effective, contextually tailored procedures in sustainable and integrated solid waste management in developing countries. Specifically, a deeper understanding is needed of how socioeconomic, cultural, and political factors influence waste management practices in different urban communities. Thus, the focus is on answering the following research question: What factors predict waste separation in the population of Bogota in 2021? To address the previous question, data from the 2021 Environmental Culture Survey conducted by the Mayor's Office of Bogota, consisting of 266,994 entries.

It is noteworthy that Bogota faces significant challenges in waste management, with waste generation increasing from 0.2 to 1 kg per person per day (Rodríguez-Díaz et al., 2022). According to Greenpeace Colombia, the city produces over 9,000 tons of waste daily, of which approximately 3,000 tons could be recycled. However, the majority of this waste ends up in the Doña Juana landfill, while only 1,530 tons are recycled (Greenpeace, 2023). Furthermore, there are residential public sites in Bogota where garbage accumulates, causing disruption to neighboring communities, as evidenced in Figure 1.

The study investigates the factors influencing household waste separation and recycling in Bogota, aiming to contribute to the development of effective and differentiated environmental policies by providing scientific evidence. Data from the 2021 Environmental Culture Survey are analyzed using regularized logistic regression LASSO to identify determinants of waste separation. Additionally, a more detailed exploration of the factors predicting waste separation practices in different urban communities of the city is conducted. The impact of waste management infrastructure, such as the availability of recycling bins, is examined. The LASSO algorithm was chosen for its advantages, including automatic feature selection, multicollinearity reduction, regularization to prevent overfitting, computational efficiency, and flexibility in various modeling problems (Hastie et al., 2001; James et al., 2013).

Numerous studies have emphasized the importance of understanding decision-making processes in this field and promoting active citizen engagement (Chavolla, 2023; Gutiérrez García et al., 2022). In this context, Salah et al. (2020) and Zahid (2024) demonstrated the significance of applying the principles of reduce-reuse-recycle in developing countries to address waste minimization and environmental objectives.

Following Fogt Jacobsen et al. (2022) in the field of waste recycling, the Theory of Planned Behavior and the Theory of Reasoned Action are widely used because they focus on consumer motivation, which is reflected in their behaviors. According to these theories, motivational factors include attitudes and social norms related to behavior, which can be intrinsic or extrinsic. In addition to motivation, consumers must have the capacity to perform the desired behavior, which involves possessing the skills, habits, knowledge, and resources necessary for action. These authors also pointed out that opportunity refers to the objective conditions for carrying out the behavior, such as convenience in terms of time and place. Optimizing these conditions can increase the likelihood that consumers will exhibit sustainable behaviors. However, contextual barriers can hinder the adoption of sustainable behaviors.

In this sense, the Theory of Planned Behavior and the Theory of Reasoned Action are related to various factors that influence the intention to carry out sustainable behaviors. Among these factors, scientific literature has outlined several that affect sustainable behaviors (Vesely & Klöckner, 2020). These factors include motivation (Bui et al., 2022), environmental knowledge (Larios-Gómez, 2019; Moh & Manaf, 2017; Tamar et al., 2020), cultural influences (Zhao & Chen, 2021), socioeconomic status (Abushammala & Ghulam, 2022; Padilla & Trujillo, 2017), social dynamics (Jatau & Binbol, 2020; Pongpunpurt et al., 2022), inadequate infrastructure (Pérez, 2019), social perceptions (H. Q. Nguyen et al., 2018), cultural, moral, and religious aspects (Begum et al., 2021), sociodemographic and economic factors (Chirilli et al., 2022; Dimitrova et al., 2022), community-authority coordination (Pérez, 2019), and waste disposal practices (T. T. T. Nguyen et al., 2022; Sukholthaman & Sharp, 2016). Additionally, family life and neighborhood context also influence waste disposal practices. The age composition of the family and the availability of waste separation facilities in the neighborhood affect households' willingness to separate waste (Zhao & Chen, 2021).

On a related note, certain studies underscore the effectiveness of economic incentives as a means to encourage recycling (Chen et al., 2022). Massarutto et al. (2019) and Song et al. (2019) have demonstrated that economic incentives can enhance motivation for waste separation. Furthermore, the enhancement of recycling infrastructure enables more effective waste sorting (Liu & Nguyen, 2020). Widyatmika and Bolia (2023) have emphasized the governmental role in promoting waste separation through policies and regulations aimed at incentivizing community recycling. Additionally, Kattoua et al. (2019) highlighted that in developing areas like Palestine, the lack of awareness and financial incentives significantly influence residents' recycling behaviors, with financial incentives being the most crucial factor motivating their active participation.

Method

Data

Utilizing open-access data from the Environmental Culture Survey conducted in Bogota in 2021 by the District Secretariat of Culture, Recreation, and Sports, the ECS offers an updated perspective on the perceptions and behaviors of Bogota citizens regarding civic culture and the environment. Administered by the Sub-Secretariat of Civic Culture and Knowledge Management, the survey encompasses four thematic areas: waste management, relationships with animals, key ecological elements, and environmental care. The survey reached over 2,200 Bogota residents aged 13 and above, spanning all 20 localities of Bogota, D.C. (Figure 2) Sampling was conducted through stratified probability sampling in multiple stages and clusters, with quota controls based on age and gender groups (Secretaria Distrital de Cultura, Recreación y Deporte, 2022).

The design of the survey was conducted during November and December 2020 within the framework of the District Environmental Culture Committee. Data collection was carried out through in-person household surveys, consisting of 38 questions. The fieldwork period was divided as follows: (a) all localities (except Sumapaz): from December 29, 2020, to January 15, 2021; (b) Sumapaz: from February 16 to 20, 2021. The distribution by defined strata was based on households reported as subscribers to the electricity service. In the first stage, a simple random sampling without replacement of neighborhoods within each stratum was conducted. In the second stage, the selection of blocks to be visited in each neighborhood was made, defined as clusters within these. And the third stage involved a systematic selection of the property (Secretaria Distrital de Cultura, Recreación y Deporte, 2022).

The potential bias in this data collection could be related to the exclusion of households not subscribed to the electrical energy service. This could introduce a selection bias, as households without access to this service may have different characteristics than those included in the sample.

In tracking, distribution among surveyed individuals by gender and age was maintained, in accordance with the proportions estimated based on DANE population projections. This was associated with a target population of 6,377,631 individuals aged 13 and above residing in stratified properties in Bogota, linked to 2,136,523 estimated households according to subscriber information from the Electricity Service Information System (SUI). The sampling design was executed to attain estimates with confidence levels exceeding 95% and an overall

Table 1. The Number of Survey Respondents Per Locality.

NEIGHBORHOOD	SURVEY RESPONDENTS
Antonio Nariño	54
Barrios Unidos	108
Bosa	156
Chapinero	94
Ciudad Bolívar	327
Engativá	114
Fontibón	93
Kennedy	191
La Candelaria	64
Los Mártires	1
Puente Aranda	30
Rafael Uribe Uribe	74
San Cristóbal	111
Santa Fe	3
Suba	134
Sumapaz	261
Teusaquillo	91
Tunjuelito	49
Usaquén	194
Usme	133

Source. Own elaboration based on the Environmental Culture Survey (Secretaria Distrital de Cultura, Recreación y Deporte, 2022).

sampling error of 2.0%, employing a stratified probability sampling methodology, multi-stage by clusters, and with quota controls for gender and specific age groups (Table 1) (Secretaria Distrital de Cultura, Recreación y Deporte, 2022).

Variables

The variable of interest was the question regarding the frequency at which respondents separated waste in their households. The predictors are listed in Appendix 1. These predictors encompass aspects such as sociodemographic and economic factors, environmental knowledge, economic incentives and regulations, cultural context, and infrastructure for recycling.

Algorithm

A logistic regression model was employed using the LASSO regularization algorithm, which is renowned for its ability to construct accurate and efficient statistical models. Unlike traditional regression methods, LASSO utilizes an automatic feature selection technique that reduces the variable set by eliminating those less relevant to prediction. This, combined with its ability to address multicollinearity and prevent overfitting, positions it as a powerful tool for data analysis. Additionally, LASSO is highly flexible and computationally efficient, making it suitable for analyzing large datasets in diverse contexts (Geng et al., 2023; Hastie et al., 2001; Hu et al., 2021; Ravindra et al., 2023). The hyperparameter λ, which regulates the penalty, was estimated; higher values of . λ are associated with a greater number of excluded predictors (James et al., 2013). Orange Data Mining (Siqueira Alencar, 2023) was utilized for the analysis (Siqueira Alencar, 2023).

Belloni et al. (2016) demonstrated that the penalized objective function of LASSO for the logit model is described as follows:

$$M_l = \sum_{j=1}^{s} w_j f(y_j \beta_0 + x_j \beta^{'}) + \lambda \sum_{i=1}^{f} k_i \mid \beta_i \mid$$

s corresponds to the number of observations, represents the normalized observation-level weighting, is the likelihood contribution for the logistic regression model logit, βo is the intercept, x_j is the covariate vector, λ is the regularization parameter of the algorithm, β is the coefficient vector, K_i are the coefficients' level weights.

The logit model is presented as follows:

$$f\left(\beta_0 + x_j \beta^{'}\right) = -y_j \left(\beta_0 + x_j \beta^{'}\right) + ln(1 + \exp\left(\beta_0 + x_j \beta^{'}\right))$$

In Orange Data Mining, the accuracy coefficient in a logistic regression LASSO is calculated using the following formula:

$$\text{Accuracy} = \left(\text{True positives} + \text{True negatives}\right) / \left(\text{Total cases}\right)$$

Where:
True positives: Cases that were correctly classified as positive by the model.
True negatives: Cases that were correctly classified as negative by the model.
Total cases: The total number of cases in the dataset.

For the data analysis, the software Orange: Data Mining Toolbox in Python (Demsar et al., 2013), version 3.36, was employed. Several widgets were used, which are specialized modules designed to perform specific data analysis tasks, such as logistic regression, data table, test and score, and preprocessing.

To perform sensitivity analysis, we utilized the regularization parameter C, which governs the strength of penalization. A higher C value implies stronger penalization, potentially resulting in a simpler model, while a lower value implies weaker penalization, potentially leading to a more complex model. We tested different values of this parameter to assess the model's robustness. Additionally, we applied 5-fold cross-validation, a

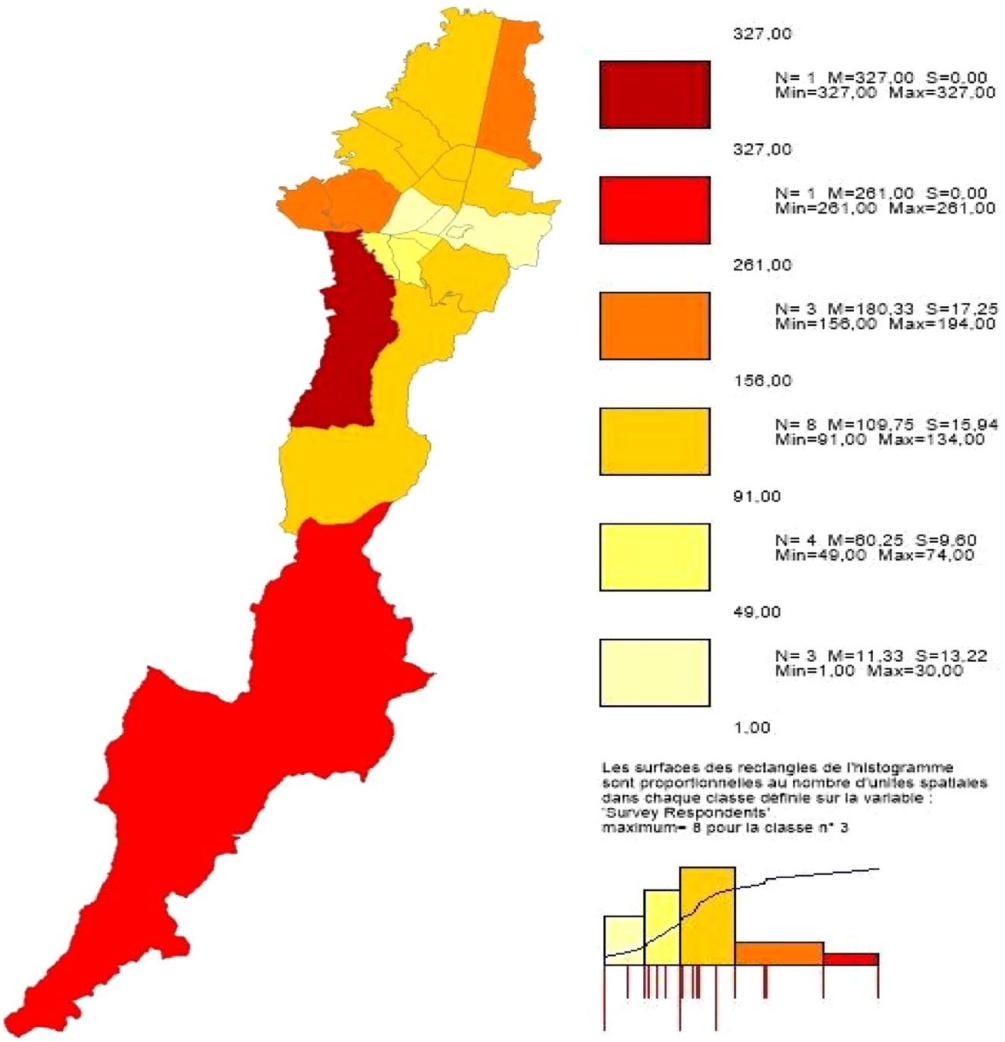

Figure 2. Number of Survey Respondents Per Locality.
Source. Own elaboration using Philcarto (Waniez, 2024). N: Number of localities. M: Average number of respondents in the category. S: Standard deviation of the number of respondents in the category. Min: Minimum. Max: Maximum.

valuable technique for evaluating the performance of a Lasso logistic regression model reliably and robustly.

Results

We standardized the data using the mean and standard deviation, which is a common and effective normalization technique to mitigate the effect of outliers in Lasso regression. Standardizing the data achieves the following: (a) Reduction in Distance, (b) The Lasso algorithm becomes less susceptible to magnitude variations in variables; (c) The data distribution approximates a normal distribution, reducing the risk of overfitting and facilitating the interpretation of model coefficients.

To carry out an effective sensitivity analysis of the penalty parameter C, we established a range of C values between 0.01 and 1. Subsequently, we proceeded to train models with different values of C. The metrics obtained from the different models are shown in Table 2.

The AUC (Area Under the ROC Curve) measures the model's ability to distinguish between two classes, and in this case, a gradual increase is observed as the parameter C increases, indicating that regularization enhances the model's ability to separate classes. Similarly, the CA (Accuracy) shows an increasing trend with higher values of C, reflecting improved precision of the model. The F1-score, which is a measure of precision and recall, also gradually increases with higher values of C, validating the overall improvement of the model with increased regularization (Table 2).

The PREC (Precision) and RECALL, which measure the proportion of correct positive predictions and the proportion of true positive cases correctly identified, respectively, show similar trends as C increases. On the other hand, the MCC (Matthews Correlation Coefficient), another measure of precision and recall, shows a trend similar to the F1-score, confirming the overall improvement of the model with increased regularization (Table 2).

Table 2. Performance Metrics of the Different Models.

MODEL	AUC	CA	F1	PREC	RECALL	MCC
Logistic regression C = 1	0.87	0.67	0.68	0.70	0.67	0.53
Logistic regression (1) c = .01	0.50	0.45	0.28	0.21	0.45	0.00
Logistic regression (2) C = .5	0.87	0.67	0.68	0.70	0.67	0.53

Source. Developed by the Orange Data Mining program (Demsar et al., 2013).

Considering these trends, a higher value of C, such as 1, seems more suitable for this model. 5-fold cross-validation, a common technique for evaluating performance robustly and reliably, confirms this choice. By dividing the dataset into five subsets and training/evaluating the model on each one, an average estimate of performance is obtained, avoiding overfitting and ensuring that the model generalizes well to unseen data.

Sociodemographic and Location Factors

Several patterns were observed across different locations in Bogota (Table 3 and Figure 3). Individuals residing in Usaquén, Chapinero, Barrios Unidos, Bosa, and Teusaquillo exhibited an increased likelihood of always separating waste (5.8%, 3.4%, 14%, 39.7%, and 39%, respectively). Conversely, individuals living in San Cristóbal, Usme, Suba, Antonio Nariño, Rafael Uribe Uribe, and Ciudad Bolívar experienced a decrease in the likelihood of always separating their waste by 19.2%, 34.6%, 6.4%, 15.1%, 1.5%, and 11.2%, respectively (Figure 3). It is noteworthy that these areas are predominantly inhabited by individuals from socioeconomic strata 1, 2, and 3.

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The results showed a direct relationship between the number of years an individual had lived in Bogota and waste separation. Individuals who had resided in the capital for a longer period were more likely to always separate their waste. These results support the claims of Jatau and Binbol (2020), who found that individuals who lived longer in one place recycled more. As the length of residence in Bogota increases, the probability of always separating waste increases by 3.2%, while the probability of separating waste almost always or sometimes decreases by 7.5% and 10%, respectively (Table 3).

Regarding marital status (Table 3 and Figure 4), different patterns were observed in waste separation. In the case of individuals in civil unions, it was found that the probability of always separating waste decreased by 11.2%, while the probability of doing so sometimes and rarely increased by 12.9% and 14.4%, respectively. On the other hand, married individuals showed a lower probability of almost always or never separating waste by 26.7% and 16.2%, respectively. Widowed or separated individuals, meanwhile, exhibited a decrease of 100% in the probability of never separating waste. In contrast, singles showed an increase of 33.5% in the probability of never separating waste, while the probability of always doing so decreased by 21.6%.

Regarding the highest level of education (Table 3 and Figure 5), individuals with a graduate degree with a title had a higher probability of always separating waste (53.4%) compared to other educational levels. Meanwhile, if individuals had a graduate degree without a title, incomplete undergraduate, technological, or technical studies, the probability of always separating waste decreased by 53.7%, 40.6%, 23.8%, and 9.7%, respectively. These findings are consistent with previous research, such as that of Chirilli et al. (2022), which demonstrated that consumers with the highest level of education have greater environmental awareness.

On the other hand, belonging to a racial, cultural, or ethnic group affects waste separation. Individuals who identify as indigenous or white have a lower probability of always separating their waste (6.2% and 7.6%, respectively). In the mestizo group, there was an increase in the probability of always separating their waste by 8.4%. As for individuals of African descent, the probability of never separating waste increased by 81.7% (Table 3 and Figure 6).

The findings of the waste separation study in Bogota underscore significant disparities in behavior among various demographic subgroups. Firstly, marital status and educational attainment emerge as influential factors. Individuals in common-law relationships or those who are single, along with those with lower levels of education, exhibit lower rates of waste separation. This suggests that factors such as household composition and educational background may impact

Table 3. Regression Coefficients and Probability Sensitivity Measure Sociodemographic and Economic Factors.

PREDICTOR	COEFFICIENTS				PROBABILITY SENSITIVITY MEASURE			
	ALWAYS	ALMOST ALWAYS	SOMETIMES	HARDLY EVER	ALWAYS (%)	ALMOST ALWAYS (%)	SOMETIMES (%)	HARDLY EVER (%)
Intercept	.000	−.037	.000	.000	.0	−3.6	.0	.0
Residence time	.032	−.078	−.105	.000	3.2	−7.5	−10.0	.0
Usaquén	.057	−.108	.000	.000	5.8	−10.3	.0	.0
Chapinero	.033	−.007	.000	−277696.000	3.4	−.7	.0	−100.0
San Cristóbal	−.213	.432	−.086	−164261.000	−19.2	54.0	−8.2	−100.0
Usme	−.424	.170	.776	−388428.000	−34.6	18.5	117.2	−100.0
Tunjuelito	.000	−.056	.292	.000	.0	−5.5	33.9	.0
Bosa	.335	−.462	.060	−388422.000	39.7	−37.0	6.2	−100.0
Kennedy	.000	.000	−.064		.0	.0	−6.2	
Fontibón	.000	−.039	.160	−.253	.0	−3.8	17.4	−22.3
Engativá	.000	.041	−.396		.0	4.2	−32.7	
Suba	−.066	.122	−.076	.520	−6.4	13.0	−7.3	68.2
Barrios Unidos	.131	−.499	.489	.000	14.0	−39.3	63.1	.0
Teusaquillo	.329	−.135	−.954	.570	39.0	−12.6	−61.5	76.9
Antonio Nariño	−.164	.026	.336	.271	−15.1	2.7	39.9	31.1
Puente Aranda	.000	.000	−138618.000	.000	.0	.0	−100.0	.0
La Candelaria	.000	.242	−.254		.0	27.4	−22.5	
Rafael Uribe Uribe	−.015	.000	.000	.000	−1.5	.0	.0	.0
Ciudad Bolívar	−.119	.000	.180		−11.2	.0	19.8	
Sumapaz	.000	−.246	.397	−241571.000	.0	−21.8	48.8	−100.0
Residence time	.032	−.078	−.105	.000	3.2	−7.5	−10.0	.0
Civil status								
Common-law marriage	−.118	−.013	.121	.135	−11.2	−1.3	12.9	14.4
Married	.000	.005	−.311	−.177	.0	.5	−26.7	−16.2
Separate	.000	.000	.000	−211878.000	.0	.0	.0	−100.0
Widower	.022	−.175	.000	−123874.000	2.2	−16.0	.0	−100.0
Single	−.244	.202	−.142	.289	−21.6	22.4	−13.3	33.5
Education level								
None	.000	.000	−.633		.0	.0	−46.9	
Preschool	.000	.000	.000	.000	.0	.0	.0	.0
Elementary school	.146	−.457	.263		15.7	−36.7	30.1	
Basic secondary and middle	.067	−.258	−.085		6.9	−22.8	−8.1	
Technical	−.102	.052	.000	−283926.000	−9.7	5.3	.0	−100.0
Technological	−.272	.203	.000		−23.8	22.5	.0	

(continued)

Table 3. (continued)

PREDICTOR	COEFFICIENTS				PROBABILITY SENSITIVITY MEASURE			
	ALWAYS	ALMOST ALWAYS	SOMETIMES	HARDLY EVER	ALWAYS (%)	ALMOST ALWAYS (%)	SOMETIMES (%)	HARDLY EVER (%)
University without degree	–.521	.266	.554	–.354	–40.6	30.5	74.0	–29.8
University degree	.000	–.067	–.124		.0	–6.5	–11.6	
Untitled postgraduate	–.770	.814	.143	.000	–53.7	125.6	15.4	.0
Postgraduate with title	.428	–.345	–.424	–170779.000	53.4	–29.2	–34.6	–100.0
Ethnic groups								
Afro-Colombian-Black	.000	–.203	.000	.597	.0	–18.4	.0	81.7
Rom (Gypsy)	.000	.000	.508	.000	.0	.0	66.2	.0
Indigenous	–.064	.000	.000	.000	–6.2	.0	.0	.0
Raizal	.000	.000	.000	.000	.0	.0	.0	.0
White	–.079	.064	–.151		–7.6	6.6	–14.0	
Mixed-race	.081	–.057	–.240	.000	8.4	–5.5	–21.3	.0

Source. Developed by the Orange Data Mining program (Demsar et al., 2013).

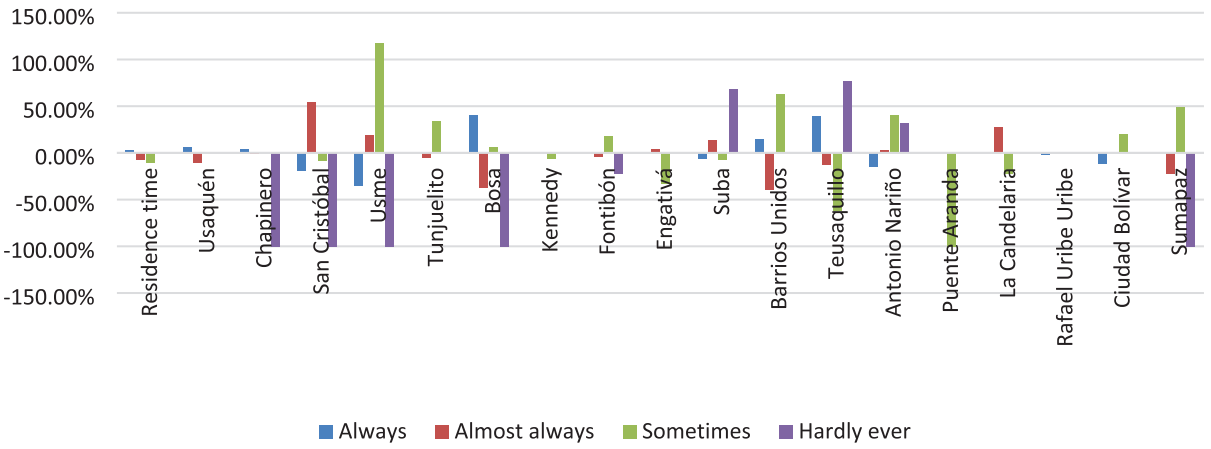

Figure 3. Graphical representation of the probability sensitivity measure by geographic location of respondents.
Source. Own elaboration.

individuals' awareness and commitment to waste separation practices. Moreover, the positive correlation between educational level and waste separation frequency highlights the role of education in fostering environmental consciousness and responsible behavior.

Furthermore, racial and ethnic identity play a notable role in waste separation behavior. Mestizos, a group often characterized by mixed heritage, demonstrate higher rates of waste separation compared to Afro-descendants and indigenous peoples. These differences may stem from cultural norms, socioeconomic factors, or access to resources, and information related to waste management. The disparities among racial and ethnic groups underscore the importance of considering cultural contexts and addressing potential barriers to waste separation within diverse communities.

The implications of these findings are significant, suggesting the need for tailored awareness campaigns and interventions that take into account the unique characteristics and

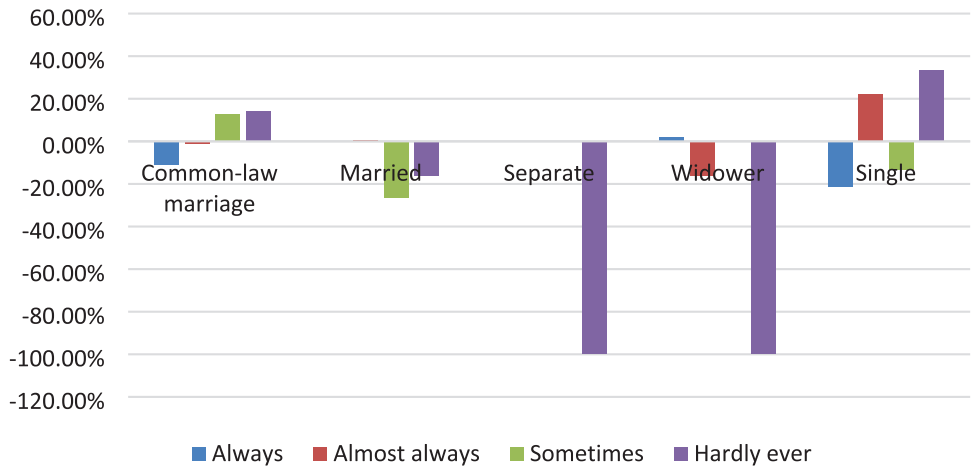

Figure 4. Graphical representation of the sensitivity measure probability by marital status.
Source. Own elaboration.

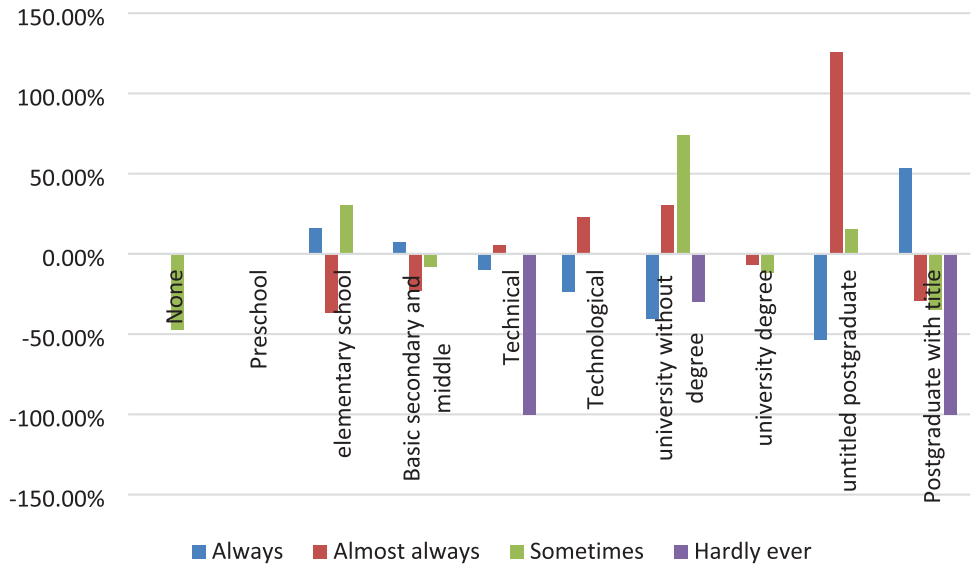

Figure 5. Graphical representation of the sensitivity measure probability by schooling level.
Source. Own elaboration.

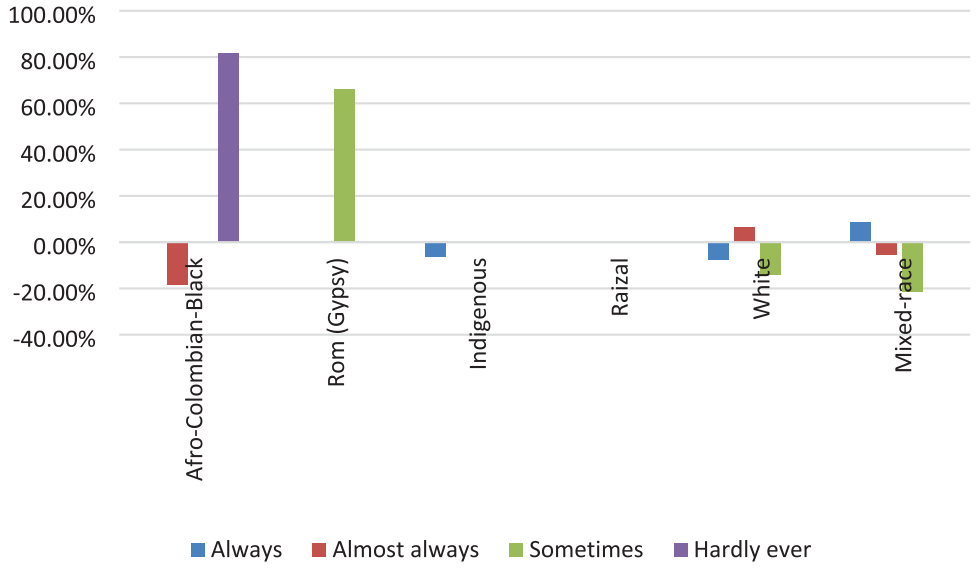

Figure 6. Graphical representation of the sensitivity measure probability by ethnic groups.
Source. Own elaboration.

challenges faced by different subgroups. By acknowledging and addressing these disparities, policymakers, and community organizers can work toward fostering a more inclusive and effective waste separation culture in Bogota. This could involve targeted educational initiatives, community engagement programs, and policy measures aimed at promoting equitable access to resources and fostering a shared sense of environmental responsibility across all segments of society.

Infrastructure for Recycling

Having only one recycling bin in the kitchen increases the probability of almost never separating waste by 81.2%, while having two bins increases the probability of doing so sometimes by 59.6%, but decreases it by 100% for never. On the other hand, people who had three or four bins were more likely to always separate waste by 35.4% and 20.2%, respectively (Table 4 and Figure 7). Overall, there is a positive relationship between the number of recycling bins and the frequency of waste separation. The more bins there are, the higher the probability that people will separate waste regularly, even always. This indicates that adequate infrastructure is key to promoting waste separation. The city could consider distributing multiple bins in residential areas or implementing innovative solutions for households with limited space.

Being sure that waste was delivered to a recycler had a significant impact on waste separation behavior. Those who were confident that their waste was being delivered for recycling showed a notable increase of 62.7% in the probability of always separating their waste. On the other hand, those who were unsure about this process showed an increase of 60.5% in the probability of separating the waste, suggesting a strong influence of trust in the recycling system on waste separation behavior (Table 4). The city must improve transparency and communication about the recycling system to build trust among citizens.

Furthermore, if people know the schedule and days of the recycling route, the probability of them never separating their waste decreases by 37%. This underscores the importance of having effective and reliable waste management channels (Table 4).

Among the difficulties in separating waste, the model showed that when it is challenging to ensure that all household members practice waste separation, the probability of always doing waste separation decreases by 34.7%, while doing it sometimes increases by 89.1%. Additionally, limited space availability makes it difficult to incorporate multiple waste bins, increasing the likelihood of never separating waste by 4.2%. Difficulty in understanding the classification of recyclable and non-recyclable waste increases the probability of separating waste by 17.3% and decreases the probability of doing it sometimes by 24.3%. The absence of a specific collection system for recycling increases the probability of almost always separating waste by 98.1% (Table 4). These implications highlight the importance of addressing the identified barriers to promote more effective waste separation practices in Bogota. By improving education and communication about waste separation, providing practical options for households with limited space, and establishing specific collection systems for recycling, the city can foster a culture of more sustainable waste management.

Although certain variables such as lack of cleanliness in the environment, habit formation, laziness, lack of time, collaboration, lack of financial resources for bag acquisition, lack of a ingrained recycling culture, difficulty washing recyclable materials, and lack of suitable containers were not found to be significant in this study, they remain fundamental aspects to consider in the context of household recycling challenges. In the specific case of Bogota, it appears that its residents do not perceive them as latent obstacles to waste separation (Table 4).

Environmental Awareness

People who prefer to use bicycles increase the probability of never separating their waste by 14.7% and decrease the probability of doing so always by 1.8%. These findings suggest that not all pro-environmental behaviors necessarily align. It seems that the environmental awareness of some individuals is directed toward specific areas, which may indicate the presence of selective environmental priorities or concerns (Table 5).

Concern for environmental impact emerges as a significant intrinsic motivation for waste separation, demonstrating a 45.8% increase in the likelihood of always doing so and a 38.9% decrease in the likelihood of never doing it. This connection rooted in environmental responsibility and planet care drives a stronger commitment to the practice. On the other hand, the integration of waste separation into cultural traditions and customary practices shows a substantial 122.7% increase in the likelihood of always doing it, highlighting the importance of its ingraining in culture for lasting adoption. However, motivations such as support for recycling workers and legal compliance show lesser positive impact, evidenced by an increase in the likelihood of rarely or never separating, suggesting that extrinsic motivations may not be effective in fostering consistent separation. Lastly, the maintenance of structure and organization, while not inherently environmental, contributes to practice adoption by reducing the likelihood of never doing it by 100%. (Table 5 and Figure 8).

The results highlight the importance of addressing motivational and cultural factors in recycling policies. While separating waste due to its positive environmental impacts or as part of a cultural tradition is associated with a higher likelihood of consistent separation, regulatory compliance tends to result in lower participation in recycling. This underscores the need for awareness campaigns that emphasize the environmental benefits of recycling.

Table 4. Regression Coefficients and Probability Sensitivity Measure of Factors Related to Recycling Infrastructure.

PREDICTOR	COEFFICIENTS				PROBABILITY SENSITIVITY MEASURE			
	ALWAYS	ALMOST ALWAYS	SOMETIMES	HARDLY EVER	ALWAYS (%)	ALMOST ALWAYS (%)	SOMETIMES (%)	HARDLY EVER (%)
Number of containers in the kitchen to recycle								
1	–.448	.188	.594		–36.10	20.70	81.20	
2	–.069	0	.467	–1466	–6.70	.00	59.60	–100.00
3	.303	–.245	–.069	–.571	35.40	–21.70	–6.70	–43.50
4	.184	–.269	0	0	20.20	–23.60	.00	.00
You are sure that the waste that can be used is delivered to a recycler								
Yes	.487	–.163	.000	.000	62.7	–15.0	.0	.0
No	.000	.000	.473		.0	.0	60.5	
Difficulty separating waste								
It is difficult to ensure that everyone in the household practices waste separation	–.426	.637	.000	.000	–34.7	89.1	.0	.0
Limited space availability makes it difficult to incorporate multiple trash receptacles	–.127	.211	.105	.041	–12.0	23.5	11.1	4.2
It is challenging to understand the classification of recyclable and non-recyclable waste	.160	.000	–.279		17.3	.0	–24.3	
The absence of a specific collection system for recycling	–.137	.684	.000	.000	–12.8	98.1	.0	.0
At your home. There is a waste collection route for recycling								
Yes	.000	–.061	–.082	.000	.0	–5.9	–7.9	.0
No	.000	–.135	.000	.561	.0	–12.6	.0	75.3
Knowledge of the days and hours of the recycling route								
Yes	.005	.000	–.108	.315	.5	.0	–10.3	37.0
No	.000	–.003	.093	.000	.0	–.3	9.8	.0
Meet the recycler who stops by your home								
Yes	.030	–.027	–.058	–.985	3.0	–2.7	–5.7	–62.6
No	–.006	.000	.000	.000	–0.6	.0	.0	.0
Trust the recycler who passes by your home								
Yes	.002	.000	–.308	.582	.2	.0	–26.5	79.0
No	–.257	.071	.184	.000	–22.6	7.4	20.2	.0

Source. Developed by the Orange Data Mining program (Demsar et al., 2013).

The analysis conducted has identified several variables that are not significant as reasons for recycling. While these variables may be tangentially related to the activity, they do not capture the intrinsic motivations that drive people to actively recycle in Bogota. These reasons include active participation in recycling work, teaching children, maintaining hygiene,

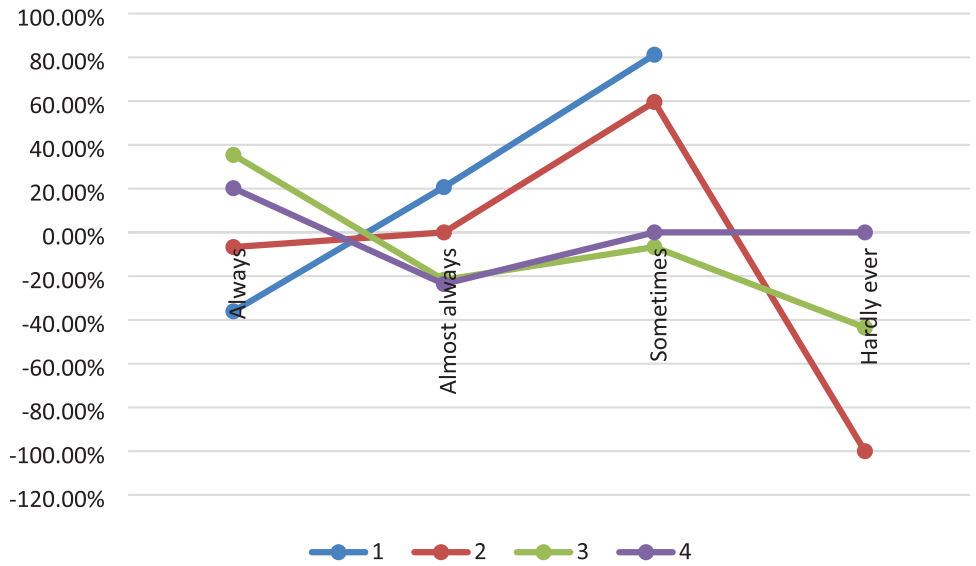

Figure 7. Graphical representation of the probability sensitivity measure by number of recycling garbage cans.
Source. Own elaboration.

Table 5. Regression Coefficients and Probability Sensitivity Measure of Factors Related to Environmental Awareness.

PREDICTOR	COEFFICIENTS				PROBABILITY SENSITIVITY MEASURE			
	ALWAYS	ALMOST ALWAYS	SOMETIMES	HARDLY EVER	ALWAYS (%)	ALMOST ALWAYS (%)	SOMETIMES (%)	HARDLY EVER (%)
He prefers to use his bicycle	–.018	.047	–.081	.137	–1.8	4.9	–7.8	14.7
Reasons to recycle								
Due to its positive impacts on the natural environment	.377	.000	.000	–.493	45.8	.0	.0	–38.9
With the aim of providing support to recycling workers	–.003	.095	.623	.085	–.3	9.9	86.5	8.8
In response to compliance with legislation that requires it	.000	–.097	.618	.419	.0	–9.2	85.4	52.0
In order to maintain the structure and organization	.000	–.231	.000	–380839.000	.0	–20.6	.0	–100.0
As part of a cultural tradition and customary practice	.800	–.069	–204401.000	.000	122.7	–6.6	–100.0	.0
Do you think that most Bogota residents separate their waste at home?								
Yes	–.060	.076	.000	.000	–5.8	7.8	.0	.0
No	.000	–.124	.254	.000	.0	–11.7	29.0	.0
In pandemic separated waste								
Yes	.000	.000	.000	–.487	.0	.0	.0	–38.6
No	.053	.000	–.180	.000	5.4	.0	–16.5	.0

(continued)

Table 5. (continued)

PREDICTOR	COEFFICIENTS				PROBABILITY SENSITIVITY MEASURE			
	ALWAYS	ALMOST ALWAYS	SOMETIMES	HARDLY EVER	ALWAYS (%)	ALMOST ALWAYS (%)	SOMETIMES (%)	HARDLY EVER (%)
Do you donate what you no longer use?								
Yes	.000	.000	−.763	.000	.0	.0	−53.4	.0
No	−.358	−.027	.000	−.639	−30.1	−2.6	.0	−47.2
Prefer not to use a plastic straw								
Yes	.000	.000	−.137	−.474	.0	.0	−12.8	−37.8
No	−.099	.000	.000	.000	−9.4	.0	.0	.0
When she goes to the supermarket. she takes reusable bags								
Yes	.000	−.014	−.092	.000	.0	−1.4	−8.8	.0
No	−.033	.000	.000	−.806	−3.2	.0	.0	−55.3
Try to reduce your consumption of products to generate less waste								
Yes	.000	−.185	.000	.075	.0	−16.9	.0	7.7
No	−.114	.000	.020	−135675.000	−10.8	.0	2.1	−100.0
Buy food packaged in styrofoam or plastic containers								
Yes	−.206	.000	.502	.000	−18.6	.0	65.3	.0
No	.003	−.013	.000	.000	.3	−1.3	.0	.0
Practice to save energy								
Yes	.000	.000	.000	−104607.000	.0	.0	.0	−100.0
No	−.323	−.001	.732	.000	−27.6	−.1	108.0	.0
Carry out practices to save or reuse water								
Yes	−.183	.000	.000	.000	−16.7	.0	.0	.0
No	.000	−.304	.000	−.290	.0	−26.2	.0	−25.2
Participate in environmental groups								
Yes	.037	−.343	.233	−108111.000	3.8	−29.0	26.3	−100.0
No	−.102	.000	.000	.000	−9.7	.0	.0	.0
Eat vegetarian food to protect the environment = 1								
Yes	.081	−.153	.000	.000	8.4	−14.2	.0	.0
No	−.167	.000	.209	−.197	−15.4	.0	23.3	−17.9
Buy products in organic markets								
Yes	.000	−.133	−.093	.680	.0	−12.5	−8.9	97.5
No	−.169	.068	.000	.000	−15.5	7.0	.0	.0
Make composting					.0	.0	.0	.0
Yes	.000	−.044	.000	−100972.000	.0	−4.3	.0	−100.0
No	.064	−.170	.053	.000	6.6	−15.7	5.5	.0

(continued)

Table 5. (continued)

PREDICTOR	COEFFICIENTS				PROBABILITY SENSITIVITY MEASURE			
	ALWAYS	ALMOST ALWAYS	SOMETIMES	HARDLY EVER	ALWAYS (%)	ALMOST ALWAYS (%)	SOMETIMES (%)	HARDLY EVER (%)
How often you reuse recyclable waste								
Always	.782	–.697	–128977.000	–258777.000	118.5	–50.2	–100.0	–100.0
Almost always	–.713	.531	.045	–183533.000	–51.0	70.1	4.6	–100.0
Hardly ever	–.332	.000	.000	.000	–28.2	.0	.0	.0
Never	.000	–.493	–.201	.579	.0	–38.9	–18.2	78.4
Do you agree that it does not matter to throw garbage into the Bogota River because it is very dirty?								
Strongly disagree	–.074	.251	.000	.000	–7.1	28.5	.0	.0
In disagreement	.238	–.099	–.080	.044	26.9	–9.4	–7.7	4.5
Agree	.000	–.131	.426	–118989.000	.0	–12.3	53.1	–100.0
Totally agree	.000	–.057	.000	167792.000	.0	–5.6	.0	#N¡NUM!
Do you agree that since there are no recycling systems in all of Bogota. it doesn't matter if I recycle?								
Strongly disagree	.262	–.362	–.143	.000	29.9	–30.4	–13.3	.0
In disagreement	–.113	.081	.043	.233	–10.7	8.4	4.4	26.2
Agree	.000	–.043	.108	–.241	.0	–4.2	11.4	–21.4
Totally agree	.180	–.124	.000	–490695.000	19.8	–11.7	.0	–100.0
Do you agree that your efforts do not contribute since the industries are the ones that contribute the most pollution?								
Strongly disagree	–.029	.000	.018	.078	–2.8	.0	1.8	8.2
In disagreement	.000	.000	.000	–237888.000	.0	.0	.0	–100.0
Agree	.054	–.115	–.172	.000	5.6	–10.9	–15.8	.0
Totally agree	.074	.000	–.345	–.199	7.7	.0	–29.2	–18.0
What is the potential of the following people or entities to contribute to the protection of the environment?								
Yourself					.0	.0	.0	.0
Much		–.158	–.195	.000	.0	–14.6	–17.8	.0
The rest of the citizenry								
Much	–.420	.332	.000	.000	–34.3	39.3	.0	.0
Little	.000	–.084	–.115	–.195	.0	–8.1	–10.9	–17.7
None	.365	.000	–126523.000	.000	44.1	.0	–100.0	.0
c. The city government					.0	.0	.0	.0
Much	.334	–.316	.000	–25516.000	39.7	–27.1	.0	–100.0
Little	–.021	.107	–.069	.000	–2.1	11.2	–6.7	.0
none	.000	.000	.000	–.753	.0	.0	.0	–52.9
d. The national government								
Much	–.065	.000	–.284	.000	–6.3	.0	–24.7	.0
Little	.000	–.285	.150	–.776	.0	–24.8	16.2	–54.0
None	.000	–.163	.000	–257772.000	.0	–15.1	.0	–100.0

(continued)

Table 5. (continued)

PREDICTOR	COEFFICIENTS				PROBABILITY SENSITIVITY MEASURE			
	ALWAYS	ALMOST ALWAYS	SOMETIMES	HARDLY EVER	ALWAYS (%)	ALMOST ALWAYS (%)	SOMETIMES (%)	HARDLY EVER (%)
e. Companies					.0	.0	.0	.0
Much	.000	−.043	.000		.0	−4.2	.0	
Little	.043	−.034	−.013	−.809	4.4	−3.4	−1.3	−55.5
None	−.259	.000	.650	.000	−22.9	.0	91.6	.0

Source. Developed by the Orange Data Mining program (Demsar et al., 2013).

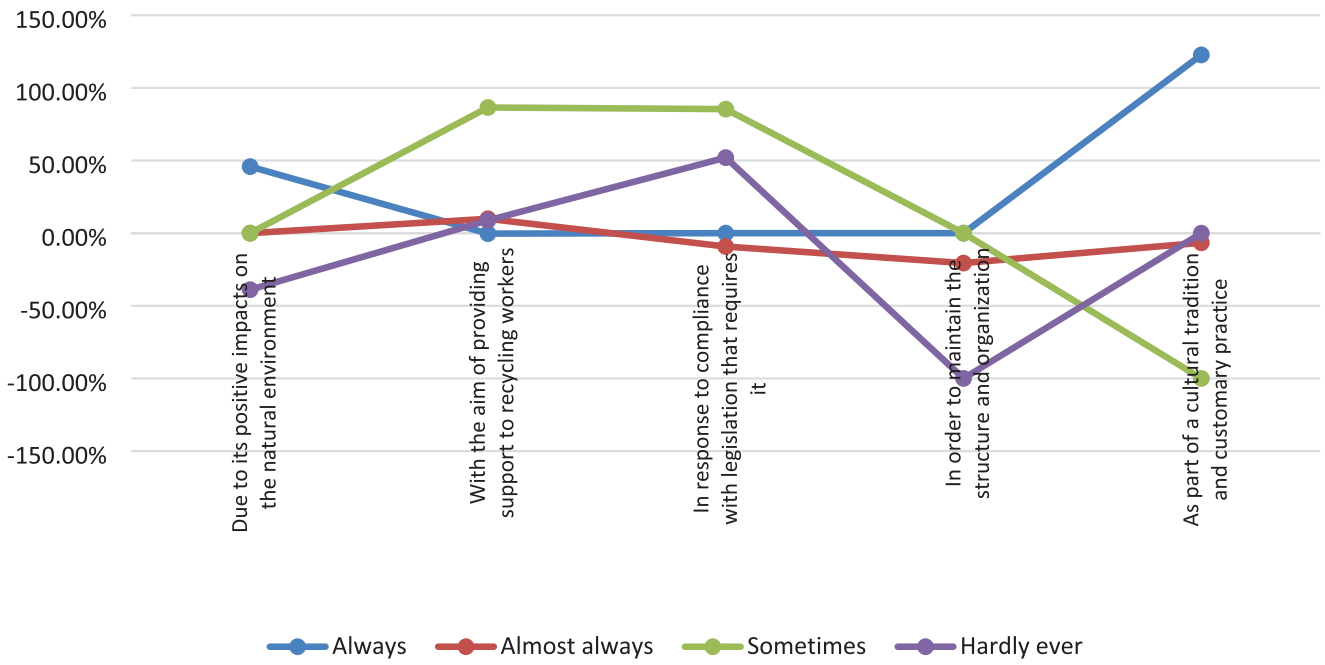

Figure 8. Graphical representation of the probability sensitivity measure for reasons to recycle.
Source. Own elaboration.

personal preference, school education, using recycling as a form of distraction, earning income, resource utilization, cultural influence, performing tasks, reducing public services, and promoting the welfare of farm animals.

When considering the alignment of other pro-environmental behaviors with waste separation, several noteworthy findings emerged. Individuals who donate unused items are less likely to almost never separate waste (53.4%). Opting against using plastic straws reduces the likelihood of never separating waste (37.8%). Forgoing reusable bags at the supermarket decreases the chance of never separating waste by 55.3%. Those who actively reduce their consumption to minimize waste generation demonstrate a higher likelihood of always separating waste (increasing by 10.8%) and a reduced likelihood of never doing so (decreasing by 100%). Purchasing food packaged in polystyrene foam or plastic containers lowers the likelihood of always separating waste by 18.6%, while increasing the probability of sometimes doing so by 65.3%. Engaging in energy-saving practices decreases the probability of never separating waste by 100%. Implementation of water-saving or reuse practices decreases the probability of always separating waste by 16.7%. Participation in environmental groups decreases the probability of never separating waste by 100% and increases the likelihood of sometimes doing so by 26.3%. Opting for a vegetarian diet for environmental reasons increases the probability of always separating waste by 8.4% yet decreases the likelihood of almost always doing so by 14.2%. Choosing products from eco-friendly markets significantly raises the probability of never separating waste by 97.5%. Engaging in composting activities decreases the likelihood of never separating waste by 100%. Reusing recyclable waste consistently boosts the probability of always separating waste by 118.5%. These findings

underscore the considerable impact of various pro-environmental behaviors on waste separation practices, illuminating the intricate and interconnected nature of attitudes and actions toward environmental conservation (Table 5).

The findings reveal a close relationship between various pro-environmental behaviors and waste separation practices, emphasizing the intricate interconnection between attitudes and actions toward environmental conservation. They imply the necessity of educational programs and policies that encourage responsible consumption, reduce plastic usage, and promote sustainable alternatives, alongside economic incentives for adopting pro-environmental practices. Furthermore, they underscore the value of supporting community initiatives and recognizing the interdependence among different sustainable behaviors to achieve effective waste management and a positive environmental impact.

Discussion

It is worth noting that proper waste separation is a problem that district and national authorities must address urgently in Bogota due to its potential benefits for water, air, and soil. Regarding water, waste separation can reduce pollution by diverting waste from landfills, thus preventing the leaching of harmful chemicals into the soil and eventually into water sources. In terms of air quality, recycling processes typically produce fewer emissions than the production of new materials, potentially leading to cleaner air and reduced pollution. Concerning soil preservation, waste separation and recycling can prolong the lifespan of landfills by diverting waste from them, as well as help conserve natural resources such as trees and metals. However, these are potential benefits contingent upon the efficiency of recycling processes and the overall waste management system, underscoring the need for effective policies to address this issue.

Our results demonstrate a direct relationship between the length of time individuals have lived in Bogota and their likelihood of consistently separating waste. This aligns with previous research (Jatau & Binbol, 2020), indicating that longer-term residents tend to recycle more frequently.

Distinct patterns in waste separation behaviors were observed across different localities of Bogota. Residents of Usaquén, Chapinero, Barrios Unidos, Bosa, and Teusaquillo exhibit higher probabilities of consistent waste separation. Conversely, residents in San Cristóbal, Usme, Suba, Antonio Nariño, Rafael Uribe Uribe, and Ciudad Bolívar show lower probabilities. These areas are predominantly inhabited by individuals from socioeconomic strata 1, 2, and 3, highlighting the influence of socio-demographic factors on waste management practices (Padilla & Trujillo, 2017). For localities exhibiting a lower inclination toward waste separation, we advocate for a multifaceted strategy. This approach entails tailored educational campaigns emphasizing the enduring advantages of waste separation, considering socio-economic, cultural, and behavioral nuances specific to each locality. Furthermore, we underscore the significance of increased investment in low-income areas, prioritizing the development of recycling infrastructure, educational initiatives, and incentive schemes.

Socio-demographic factors, such as marital status and level of education, also influence waste separation behaviors. Individuals with a graduate degree with a title have a higher probability of always separating waste compared to other educational levels. Marital status also shows varying patterns, with civil union individuals exhibiting decreased probabilities of consistent waste separation. The results confirm the findings of previous research that showed factors such as education level and marital status affect sustainable practices (Abushammala & Ghulam, 2022).

Belonging to a racial, cultural, or ethnic group affects waste separation behaviors. Individuals identifying as indigenous have lower probabilities of always separating waste, while those of African descent exhibit increased probabilities of never separating waste. These findings suggest the need for culturally sensitive approaches to waste management initiatives.

Based on the findings, we suggest implementing specific educational campaigns targeting population segments such as low-income areas, single individuals, individuals with lower educational levels, Afro-descendant, and indigenous communities. These campaigns should meticulously tailor messages and communication channels to address the characteristics and needs of each group.

Several challenges to waste separation were also identified. Difficulty in ensuring household-wide participation in waste separation decreases the probability of always doing so by 34.7%. Additionally, limited space availability for multiple waste bins increases the likelihood of never separating waste by 4.2%. Addressing these challenges through targeted interventions, such as educational campaigns and infrastructure improvements, could enhance waste management practices, as Zhao and Chen (2021) indicated.

The quantity of trash containers accessible in the household kitchen is a decisive factor in waste separation, emphasizing the need for suitable recycling infrastructure. The possibility of recycling falls when only one or two containers are available; however, having three or four containers enhances the likelihood of trash separation. These findings back up the ideas of Bui et al. (2022), Eitel (2022), Pegels et al. (2022), and Widyatmika and Bolia (2023), who emphasize the impact of external factors such as infrastructure, community participation, and trust in the government on individual waste separation and management practices.

In this context, we recommend exploring innovative solutions for households with limited space, such as collapsible containers or customized collection systems. Additionally, it is essential to improve access to recycling points, especially in peripheral and low-income areas. Environmental campaigns should address the challenge of family participation by developing strategies aimed at involving all household members in waste separation.

It's worth noting that when individuals are aware of or trust the recycling personnel in their area, the probability of consistently separating waste increases. Conversely, if the recycler is unknown, the likelihood of proper waste separation decreases, emphasizing the importance of engaging with key individuals to promote pro-environmental behaviors. These findings align with those of Coletto and Carbonai (2023), who found that the credibility of recyclers influences sustainable behaviors.

Confidence in the waste recycling system emerges as a significant factor influencing behavior. Individuals assured that their waste is delivered for recycling show a substantial 62.7% increase in the probability of always separating waste. Conversely, uncertainty regarding this process results in a 60.5% increase in the probability of not separating waste. This underscores the importance of transparent and reliable recycling processes in promoting sustainable behaviors.

At this juncture, it's noteworthy that Bogota has informal waste collectors who lack job security and resources to integrate into the city's official waste management system, underscoring the absence of formal incorporation of recycling as a standard practice. Despite existing recycling initiatives in the city, they function autonomously from the official waste management system. Recycling efforts primarily occur through the collecting population, operating adjacent to the official system, while citizens voluntarily engage in waste separation within their households (Martinez Rodríguez, 2023). The situation described above underscores the lack of formal integration of recycling as a standard practice underscores the need for policies that foster the inclusion of waste management in urban planning and civic culture. This entails not only implementing infrastructure and recycling programs but also raising awareness about the environmental and social benefits of recycling, strengthening legislation to ensure compliance, and promoting greater community involvement in these initiatives, rather than simply informing about the benefits of recycling.

Motivations for waste separation vary among individuals. Separating waste due to its positive impacts on the natural environment increases the likelihood of consistent separation by 45.8%. However, separating waste to support recycling workers results in a higher probability of hardly ever separating waste, indicating the presence of selective environmental priorities or concerns among residents (Pérez, 2019).

On the other hand, the analysis revealed that when people choose to separate waste due to their belief in environmental benefits, habit, or tradition, or disagree with the notion that it does not matter to dispose more waste into the Bogota River because it is already polluted, the probability of recycling increases. In this regard, it is demonstrated for Bogota that culture plays an important role in behaviors and attitudes related to the environment. Furthermore, education on waste separation can influence how individuals dispose of their waste.

Avoiding the use of plastic straws and using reusable bags at supermarkets, or participating in environmental associations, are associated with a higher likelihood of consistently separating waste. Conversely, the lack of intention to consume fewer products and purchase food packaged in plastic or Styrofoam containers to help the environment, or failure to conserve energy, reduced the likelihood of waste separation. The results of this study support the importance of environmental awareness as the primary motivator to promote sustainable recycling practices at home, in line with the approach of Tamar et al. (2020).

Based on the previous findings, the study reveals a strong connection between intrinsic motivation and waste separation, suggesting that environmental concern, personal responsibility, and the desire to contribute to the environmental cause are key factors in fostering waste separation. While intrinsic motivation plays a predominant role, extrinsic motivation can also influence waste separation, as seen in external factors such as supporting recycling workers and lacking intent to change consumption habits for environmental protection. On the other hand, contextual motivation unveils the significance of trust in the recycling system, as well as personal relationships and community trust. Additionally, culture and education about waste separation play a crucial role in influencing attitudes and behaviors toward recycling. These findings underscore the complexity of the factors driving waste separation participation and emphasize the need to address both external and contextual aspects to promote sustainable waste management practices.

The study reveals unexpected findings regarding how a preference for cycling doesn't necessarily align with waste separation, challenging the previous association between bicycle use and environmental consciousness. This may be because the choice of cycling among young adults as a transportation option is influenced by various socio-economic and demographic factors (Li et al., 2024), which are not always in line with environmental awareness. Moreover, it questions intrinsic and extrinsic motivation as sole drivers for waste separation, consistent with debates about the direct relationship between knowledge, attitudes, and pro-environmental behavior (Gifford, 2014).

This study presents significant theoretical implications that both expand and challenge the planned behavior and reasoned action theories in the context of recycling in the following aspects:

(i) Complexity of Motivations: Motivations for waste separation go beyond the intrinsic-extrinsic dichotomy, and factors such as confidence in the recycling system, social responsibility, and alignment with other pro-environmental behaviors influence separation. This is because these motivations are not fully captured by traditional theories.

(ii) Importance of Context and Barriers: Lack of access to infrastructure or the presence of contextual barriers can hinder action, even with high motivations. It is noteworthy that theories must consider these contextual dimensions to better explain separation behavior.

(iii) Interconnection of Sustainable Behaviors: Waste separation is associated with other pro-environmental behaviors, such as reducing consumption, composting, and reusing. This interconnection suggests that theories should focus on promoting sustainable lifestyles overall, rather than isolated behaviors.

In this regard, the findings of this research challenge theories by not fitting perfectly into the intrinsic-extrinsic dichotomy, demonstrating that motivations can be more complex and contextual, and suggesting that accurate prediction of behavior requires a deeper understanding of motivations and context.

The findings of the waste separation study in Bogota offer valuable lessons for implementation in similar urban settings. They highlight the need to develop differentiated educational programs and campaigns, identifying population segments with lower propensity for waste separation, while considering socio-economic, cultural, and behavioral patterns across different sectors of the city. Emphasizing vulnerable areas is crucial to prioritize investment in recycling infrastructure, educational campaigns, and incentive programs in low-income areas. Addressing the improvement of recycling infrastructure is another key issue to tackle. Additionally, recognizing recyclers and integrating recycling into the community through implementing supportive policies that encourage their active participation in the recycling process is essential.

The study on waste separation in Bogota provides a fundamental insight into the behaviors and factors influencing waste management. However, it's crucial to acknowledge the limitations to interpret the findings accurately and guide future research. Firstly, the results are confined to Bogota and may not be generalizable to other urban contexts with different sociocultural and political landscapes. Additionally, the cross-sectional design of the study doesn't allow for establishing causal relationships between identified factors and waste separation practices. Self-reported data might be prone to social desirability biases, highlighting the need to validate this data with objective methods. To address these limitations, future research could conduct comparative studies in diverse urban settings, employ longitudinal designs, and utilize mixed-methods approaches.

Conclusion

This study on waste management practices in Bogota highlights several key findings. Long-term residents demonstrate a greater inclination to consistently separate waste, underscoring the impact of residency duration on recycling behaviors. Additionally, the results unveiled diverse patterns across neighborhoods, with evident influence from socio-economic factors. The research also emphasizes the role of sociodemographic factors such as education level, marital status, and ethnic background in waste separation practices. Identified challenges include family engagement and container space availability.

Furthermore, this study emphasizes the importance of trust in the recycling system and individual motivations for waste separation. The results challenge existing theories by revealing the complexity of motivations for waste separation, as well as the significance of contextual factors and barriers, and the interconnectedness of sustainable behaviors. These findings suggest that accurately predicting behavior requires a deeper understanding of motivations and context, challenging traditional dichotomies and underscoring the need for more holistic approaches to promote sustainable waste management practice.

The findings presented in the study have direct implications for the development of effective environmental policies in Bogota. A key recommendation is to implement differentiated educational programs that address the specific needs of various population segments, such as low-income areas, individuals with lower educational levels, and Afro-descendant and indigenous communities. These campaigns should be tailored to address the different motivators and barriers to waste separation in each demographic group. Additionally, we emphasize the importance of prioritizing the improvement of recycling infrastructure in vulnerable areas, including installing more garbage containers and expanding selective waste collection programs.

It is also crucial for district authorities to formally integrate informal waste pickers into the official waste management system, providing job security and resources for their active participation. This can be achieved through policies that recognize and support the crucial role of waste pickers in the waste separation process. In addition to this, there should be regulations ensuring transparent and reliable recycling processes to increase public confidence in the waste system, which can be achieved by implementing waste tracking and tracing systems. In line with this, we suggest introducing economic or tax incentives to encourage waste separation, along with better dissemination of waste collection schedules to facilitate household separation.

The findings of the study offer valuable insights that stakeholders, including urban planners and environmental NGOs, can leverage to enhance waste management strategies. For instance, urban planners can utilize data on diverse waste separation patterns across different areas to inform the design of specific waste collection programs. By identifying areas with lower rates of waste separation, urban planners can allocate resources to implement tailored educational campaigns aimed at raising awareness and promoting behavior change in those specific communities.

Environmental NGOs can collaborate with local authorities to develop and implement these educational initiatives, using the identification of sociodemographic factors influencing waste separation practices from the study. For example, campaigns can be adapted to resonate with the cultural beliefs and values of Afro-descendant and indigenous communities, addressing any cultural barriers to waste separation. Furthermore, urban planners and environmental NGOs can

advocate for increased investment in waste management infrastructure in marginalized neighborhoods, supporting the installation of additional garbage containers and the expansion of selective waste collection programs such as construction waste.

The conclusions drawn from this study on waste management practices in Bogota have significant implications for global environmental issues such as climate change and sustainable urban development for several reasons. Firstly, addressing waste management challenges is crucial in mitigating climate change. By promoting sustainable waste management practices, the study contributes to global efforts in combating climate change by reducing carbon footprints and fostering resource efficiency. Secondly, sustainable waste management is pivotal in achieving sustainable urban development. As cities continue to grow, waste management becomes increasingly complex. Inefficient waste management systems not only contribute to environmental degradation but also pose risks to public health and impede social and economic development.

The recommendations provided in the study, such as improving recycling infrastructure and integrating informal waste pickers, align with the goals of sustainable urban development by enhancing environmental quality, promoting inclusivity, and fostering economic opportunities in urban areas. Furthermore, the study emphasizes the importance of addressing socio-economic disparities in waste management. By tailoring educational campaigns and infrastructure improvements to meet the specific needs of different demographic groups, the research contributes to promoting social equity within urban communities. Addressing socio-economic disparities in waste management is crucial for advancing sustainable development goals, including those related to poverty alleviation, health, and well-being.

It is worth noting that this study combines the innovative use of machine learning techniques with a detailed analysis of the factors influencing household waste separation. This provides valuable information for designing more effective public policies and environmental management strategies in Bogota, and potentially in other cities. Furthermore, it may inspire future research to apply alternative machine learning algorithms to address environmental issues.

For future studies on waste separation in Bogota and other urban contexts, it is crucial to consider several specific suggestions. Firstly, employing longitudinal designs instead of cross-sectional designs would allow for a better understanding of how the identified factors impact these practices over time. Additionally, we recommend replicating the study in other cities or countries to assess the generalizability of the findings. Furthermore, we suggest validating self-reported data with objective methods and conducting comparative studies across different urban settings to identify similarities and differences in waste separation practices and influencing factors.

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Ethical Approval

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Informed Consent

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Data Availability

The data is publicly accessible and can be consulted at the following link: https://datosabiertos.bogota.gov.co/dataset/eca2021

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Appendix 1. Predictors of Waste Separation Frequency in Surveyed Households.

DIMENSION	PREDICTOR AND CATEGORIES
Sociodemographic and location factors	Residence time
	Location
	Usaquén
	Chapinero
	Santa Fe
	San Cristóbal
	Usme
	Tunjuelito
	Bosa
	Kennedy
	Fontibón
	Engativá
	Suba
	Barrios Unidos
	Teusaquillo
	Los Mártires
	Antonio Nariño
	Puente Aranda
	La Candelaria
	Rafael Uribe Uribe
	Ciudad Bolívar
	Sumapaz
	Civil status
	Common-law marriage
	Married
	Separate
	Widower
	Single
	Education level
	None
	Preschool
	Elementary school
	Basic secondary and middle
	Technical
	Technological
	University without degree
	University degree
	Untitled postgraduate
	Postgraduate with title
	Ethnic groups
	Afro-Colombian
	Gypsy
	Indigenous
	Raizal
	White
	Mestizo
Environmental awareness	Do you prefer to use your bicycle
	You are sure that the waste that can be used is delivered to a recycler
	Yes
	No
	Reasons to recycle
	Due to its positive impacts on the natural environment
	With the aim of providing support to recycling workers
	In response to compliance with legislation that requires it
	Active participation in recycling work
	In order to maintain the structure and organization
	As part of a cultural tradition and customary practice
	Teach children
	Maintain hygiene
	By personal preference
	Education at school

Appendix 1. (continued)

DIMENSION	PREDICTOR AND CATEGORIES
	As a form of distraction
	To earn income
	Use of resources
	By cultural influence
	To perform tasks
	To reduce public services
	For the welfare of farm animals
	Meet all of the above
	Do you think that most Bogota residents separate their waste at home?
	Yes
	No
	In pandemic separated waste
	Yes
	No
	Do you donate what you no longer use?
	Yes
	No
	Prefer not to use a plastic straw
	Yes
	No
	When she goes to the supermarket, she takes reusable bags.
	Yes
	No
	Try to reduce your consumption of products to generate less waste.
	Yes
	No
	Buy food packaged in styrofoam or plastic containers.
	Yes
	No
	Practice to save energy
	Yes
	No
	Carry out practices to save or reuse water
	Yes
	No

(continued)

Appendix 1. (continued)

DIMENSION	PREDICTOR AND CATEGORIES
	Participate in environmental groups
	Yes
	No
	Eat vegetarian food to protect the environment = 1
	Yes
	No
	Buy products in organic markets
	Yes
	No
	Make composting
	Yes
	No
	How often you reuse recyclable waste
	Always
	Almost always
	Hardly ever
	Never
	Do you agree that it does not matter to throw garbage into the Bogota River because it is very dirty?
	Strongly disagree
	In disagreement
	Agree
	Totally agree
	Do you agree that since there are no recycling systems in all of Bogota, it doesn't matter if I recycle?
	Strongly disagree
	In disagreement
	Agree
	Totally agree
	Do you agree that your efforts do not contribute since the industries are the ones that contribute the most pollution?
	Strongly disagree
	In disagreement
	Agree
	Totally agree
	What is the potential of the following people or entities to contribute to the protection of the environment?

(continued)

Appendix 1. (continued)

DIMENSION	PREDICTOR AND CATEGORIES
	Yourself
	Much
	Little
	None
	The rest of the citizenry
	Much
	Little
	None
	The city government
	Much
	Little
	None
	The national government
	Much
	Little
	None
	Companies
	Much
	Little
	None
Infrastructure for recycling	Number of containers in the kitchen to recycle
	1
	2
	3
	4
	At your home, there is a waste collection route for recycling
	Yes
	No
	Difficulty separating waste
	It is difficult to ensure that everyone in the household practices waste separation
	Limited space availability makes it difficult to incorporate multiple trash receptacles
	It is challenging to understand the classification of recyclable and non-recyclable waste
	The absence of a specific collection system for recycling

(continued)

Appendix 1. (continued)

DIMENSION	PREDICTOR AND CATEGORIES
	Dirty the spaces
	Lack of awareness
	Lack of haLittle
	Laziness
	Lack of time
	Lack of Collaboration/Education
	Lack of money for bags
	Lack of culture
	Difficulty in washing the material
	Not having the appropriate bins
	Forgot
	The street dwellers break the bags
	There is no recycling route
	Frequent changes in the law
	Difficulty finding colored bags
	Lack of information
	None
	All
	Knowledge of the days and hours of the recycling route
	Yes
	No
	Meet the recycler who stops by your home
	Yes
	No
	Trust the recycler who passes by your home
	Yes
	No
	Knowledge of the days and hours of the recycling route
	Yes
	No
	Meet the recycler who stops by your home
	Yes
	No

Source. Own elaboration based on the Environmental Culture Survey (Secretaría Distrital de Cultura, Recreación y Deporte, 2022).