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Why Plastic Policies Fail in Some Areas but Succeed in Others: A Cluster Analysis of Implementation Patterns in a University Campus

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Research Article

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Abstract

Implementing single-use plastic (SUP) reduction policies is critical for sustainability but remains a challenge in complex institutions due to heterogeneous compliance. This study evaluated the effectiveness of a restriction policy at the National University of Engineering in Peru, using waste characterization data from 28 ecological points before and after a six-month intervention based on diffusion and non-sanctioning monitoring. The analysis employed Wilcoxon tests for overall impact, K-Means clustering for heterogeneity, and Spearman correlations to assess behavioral patterns. Results revealed no statistically significant overall reduction in plastic bags; however, cluster analysis identified three dis-tinct implementation patterns: 'Successful' (n = 7) with significant reductions, 'Moderate' (n = 13), and 'Critical' (n = 8) where generation increased. Crucially, positive correlations were found between the variation of bags and all other SUPs, indicating a "coherent behavioral response"—integral adoption or rejection of the policy message—rather than a substitution effect. The study concludes that interventions based solely on diffusion without effective governance yield heterogeneous results driven by local context and institutional barriers. Consequently, future policies must combine clear regulations with robust enforcement mechanisms and targeted incentives to ensure full compliance. This approach not only ensures compliance but also prevents resource waste on ineffective strategies, thereby optimizing logistical and operational efforts in the long term.

Introduction

The proliferation of single-use plastics (SUP) represents a global environmental crisis, which has driven governments around the world to establish regulatory policies such as bans and taxes (Muposhi et al., 2022). These interventions have demonstrated an effective capacity to generate behavioral changes on a large scale. Notable examples include the marked reduction of 90–95% in the consumption of plastic bags following the imposition of a levy in Ireland (a tax of 15 euro cents per bag) (Foolmaun et al., 2021; Amir-ud-Din et al., 2024; Convery et al., 2007) and a considerable decrease in plastic bags on the coasts of the United States (between a 25% and 47% reduction in the proportion of coastal litter) (Papp and Oremus, 2025). Success in cases like that of Ireland has been attributed to fundamental actions in implementation, such as the conducting of exhaustive consultations and the fostering of stakeholder acceptance (Convery et al., 2007).

However, the efficacy of these policies is far from being universal, as they often lead to unintended consequences that can diminish their total impact (Muposhi et al., 2022). A recurring phenomenon is policy leakage, where consumers substitute a regulated plastic product for an unregulated one (Taylor, 2018). This effect was quantified in California, demonstrating that the reduction of 40 million pounds of carryout bags was offset by an increase of 12 million pounds in the sales of garbage bags, which represents a leakage rate of 28.5% (Macintosh et al., 2020). Analogously, an evaluation in the Australian Capital Territory revealed that the decrease in thin plastic bags was largely offset by a higher consumption of thicker alternatives, resulting in a minimal net plastic reduction of 275 tons (Macintosh et al., 2020). This substitution effect has happened similarly in institutional environments, as

demonstrated on a university campus like the University of Vermont where the ban on bottled water led to an increase in the consumption of other sugary beverages packaged in plastic (Berman and Johnson, 2015).

Growing evidence suggests that the guarantee between success and failure of these policies depends less on the type of measure implemented and more on the complexities of its enforcement and governance (Muposhi et al., 2022; GAIA, 2025). Systematic reviews have identified important barriers to success, including insufficient state capacity for monitoring and enforcement, the lack of viable and affordable alternatives, and industry resistance (Muposhi et al., 2022; GAIA, 2025; Bócoli et al., 2025; Food Standards Agency, 2025). The case of Mauritius, an island country in Africa, serves as a clear example of these challenges, where a national ban on the use of plastic bags was cataloged as a failure by 65% of the population due to poor enforcement and insufficient awareness (Foolmaun et al., 2021).

Conversely, success is strongly associated with the engagement of all stakeholders (Milbreta et al., 2025). In fact, a comparative study of 12 countries concluded that the degree of participation of the retail sector is often more critical for success than the policy instrument itself implemented (ban or levy) (Milbreta et al., 2025). Furthermore, strategic analyses suggest that positive incentives (such as subsidies to promote recyclable bags) and robust enforcement are more effective tools than purely punitive measures (such as taxes or fines) to ensure the collaboration of economic actors in the long term (Ali et al., 2021; Wang et al., 2022).

University campuses, as transcendental formative spaces of a society, are ideal scenarios to study these implementation dynamics (Oludoye and Supakata, 2024; Seblos et al., 2023). The success of any policy in this environment depends fundamentally on the awareness and behavior of the community, as has been demonstrated in studies in Kenya (Omondi and Asari, 2021). Evidence suggests that even "soft" and low-cost interventions, such as personal commitments, can be effective in reducing plastic consumption in these environments (Truelove et al., 2023; Sustainability Online, 2025), especially when policy adoption is influenced by social dynamics and factors (such as wealth, education, and social network centrality) within the institution (Yang and Kim, 2019; Yang and Kim, 2020).

However, while macro-level factors influencing policy efficacy are well documented, there is a knowledge gap in understanding how these factors operate to create markedly heterogeneous results within the same institution. Few studies have analyzed the spatial and social variability of a policy's impact to explain why it may succeed in one area of a campus while failing in another. This study addresses that gap using a waste characterization methodology combined with a cluster analysis to verify the variable efficacy of a single-use plastic reduction policy at the National University of Engineering in Peru. The objective is to identify and characterize the distinct patterns of success and failure in implementation, and to diagnose the institutional and behavioral barriers that foster this heterogeneity. The main findings reveal that, in the absence of sanctions, the community's response was not uniform nor a simple substitution, but a "coherent behavioral response" highly dependent on the local context, generating three distinct implementation patterns: critical, moderate, and successful.

Materials and methods

Study area and political context

The study was conducted at the National University of Engineering (UNI), a public university located in Lima, Peru. For the 2024-1 semester, UNI registered a student population of 11,352 (UNI, 2025), distributed across its eleven faculties: Architecture, Urban Planning, and Arts (FAUA); Science (FC); Environmental Engineering (FIA); Civil Engineering (FIC); Economic Engineering, Statistics, and Social Sciences (FIEECS); Electrical and Electronics Engineering (FIEE); Geological, Mining, and Metallurgical Engineering (FIGMM); Industrial and Systems Engineering (FIIS); Mechanical Engineering (FIM); Petroleum, Natural Gas, and Petrochemical Engineering (FIP); and Chemical and Textile Engineering (FIQT).

During the preliminary visits conducted between November (2024) and May (2025), a total of 43 food concessionaires, kiosks, and photocopy centers were identified operating within the campus. A review of the available contracts and interviews with the managers of each establishment indicated that these concessionaires operated under different contractual conditions, and none of the reviewed contracts included specific clauses requiring compliance with university environmental regulations regarding plastics.

The regulatory framework of the study is Rectoral Resolution No. 1788 – DIRECTIVE No. 010-2019-DIGA UNI (UNI, 2019), titled "Law regulating single-use plastic and disposable containers or packaging at the National University of Engineering," published on December 24, 2019. This resolution prohibits the use of single-use plastics on campus. However, although the regulation formally exists, it lacks an explicit and effectively applied protocol for enforcement and sanctions. This absence of robust governance mechanisms is a known barrier to the effectiveness of environmental policies, a situation documented in other international contexts, such as the case of Mauritius, an island country in the Indian Ocean, where poor enforcement was identified as the main cause of failure (Foolmaun et al., 2021). This particular scenario at UNI, characterized by a formal policy without coercive enforcement (low governance) and a heterogeneous population of actors (faculties, concessionaires), offers a valuable opportunity to evaluate the effectiveness of non-sanctioning interventions.

Quasi-experimental design and intervention

Given that existing literature has identified implementation as a critical factor leading to heterogeneous outcomes in plastic policies, even among countries with similar policies (Muposhi et al., 2022; GAIA, 2025), it is necessary to analyze this variability at a finer scale, such as within a single institution. Therefore, the following quasi-experimental methodology was developed. This approach allows for evaluating the impact of a policy in a real-world setting (a university campus), where complete experimental control is not feasible (Truelove et al., 2023; Botella et al., 2022).

The study design consisted of four main phases: (1) the establishment of a baseline through an initial waste characterization; (2) the design and implementation of an intervention based on dissemination within a context of low enforcement; (3) the final quantification of changes in plastic waste generation through a post-intervention measurement (pre-test/post-test design); and (4) a multilevel statistical analysis to evaluate both the overall impact and heterogeneous implementation patterns. Figure 3 summarizes the methodological flow of the study.

Between the two waste measurements (pre-test and post-test), a targeted intervention was implemented over a 2-month period. This intervention combined dissemination and monitoring strategies, approaches shown to be effective in influencing behavior in community settings (Seblos et al., 2023; Van Hau et al., 2025), especially when sanctioning measures are not applicable. The institutional barriers that prevented the application of sanctions included: (a) the absence of specific environmental clauses in current concessionaire contracts and (b) the lack of authorization from the General Directorate of Administration (DIGA) to impose penalties.

The intervention consisted of two main components:

Educational and dissemination component

In accordance with studies underscoring the importance of consumer awareness (Oludoye & Supakata, 2024), a total of 20 sensitization talks were conducted, both in-person and virtually (lasting 30–45 minutes), targeted at concessionaires, administrative staff, and students. Attendance averaged 30 people for in-person talks (FIIS, FIC, FIEE, FIQT, FIEECS) and 50 for virtual sessions (FIM, Central Pavilion), covering approximately 70% of workers and 15% of students. These talks addressed the environmental consequences of single-use plastics (bags, cups, straws, etc.) and presented available alternatives. Additionally, informative posters detailing the current regulations (Rectoral Resolution No. 1788–2019) were distributed and placed at each concessionaire point of sale. Photos of the poster delivery are provided in **Online Resource 1 (Fig. S1)**.

The alternatives proposed during the talks were as follows:

- For university concessionaires: The complete substitution of the monitored plastics (bags, straws, breakfast bottles, beverage bottles, and food containers) with kraft paper bags and natural fiber materials was proposed, an alternative recommended by the research project “Alternatives to single-use plastics in food packaging and production” due to its acceptance by various consumers (Food Standards Agency, 2025; Omondi & Asari, 2021). In line with "zero waste" models applied on other campuses such as Xi'an Shiyou University, vendors were urged not to provide takeout food by default or, when necessary, to migrate towards the use of bamboo, cardboard, or biodegradable fiber containers to minimize the impact of disposable packaging (Food Standards Agency, 2025; He & Yu, 2023). Photos of the talks given to administrative staff and concessionaires (Online Resource 1, **Fig. S2**).

- For students and workers: During the sensitization talks, the importance of voluntary individual action was emphasized (Sustainability Online, 2025). They were actively requested to try to consume food within the establishment; if unable, to bring their own container for food consumption and use reusable bottles for beverages, thus promoting a refill and reuse model that reduces dependence on single-use plastic, as indicated by the literature review conducted in the research project “Alternatives to single-use plastics in food packaging and production” (Food Standards Agency, 2025). Photos of the sensitization process (Online Resource 1, Fig. S3).

Monitoring component (Non-Sanctioning)

Periodic unannounced inspections of concessionaires were conducted. These inspections were purely observational, recording the degree of compliance and barriers reported by vendors in a standardized format (Online Resource 1, Table S1). The collected information was verbally communicated to the concessionaires. This absence of formal administrative consequences reflected the practical realities of policy implementation in contexts with low enforcement capacity. Photos of inspection activities are available in Online Resource 1 (Fig. S4).

Data collection and quantification

A pre-test/post-test design was employed. Two plastic waste characterization studies were conducted at 28 ecological points strategically distributed throughout the campus: a baseline measurement ("before") and a final measurement ("after"); all measurements were completed using a standardized format (see Online Resource 2, Table S3). Both measurements were carried out during a full week prior to the end-of-cycle academic evaluations.

Cleaning staff daily collected the contents of the bins corresponding to recyclable and non-recyclable waste from these points. The quantification of the items of interest was performed daily as follows:

- **Plastic bags, straws, and bottles**: A direct count of the number of units present in the waste bags collected from the appropriate bins was performed. Two types of PET bottles were distinguished based on their predominant use on campus: "breakfast bottles" (containers for drinks such as quinoa, maca, oats, usually < 500mL) and "water/soda bottles" (containers for water, sodas, rehydrating drinks, usually > 500mL).
- **Food containers (Tuppers)**: Disposable food containers (expanded polystyrene, polypropylene, etc.) were separated, visible food residues were removed, and the total mass (in kg) was weighed using a calibrated scale.

Photos of the characterization process are shown in Online Resource 1 (Fig. S5).

Statistical analysis

Two levels of statistical analysis were applied to evaluate the impact of the intervention. All analyses were performed using R statistical software (version 4.2.0).

Global impact assessment

To determine if there was a statistically significant change in the generation of each type of waste at the campus level, the non-parametric Wilcoxon signed-rank test was used (Botella et al., 2022; Wilcoxon, 1945). This method is standard for comparing paired samples that do not exhibit normal distribution and is used in similar contexts of waste intervention evaluation (Botella et al., 2022; Zulfa & Nugraheni, 2020; Geiger et al., 2019). This test was selected because the waste characterization data did not meet the normality assumptions required for parametric tests. The medians of the differences between the paired observations ("Before" vs. "After") were compared to determine if they were significantly different from zero.

Heterogeneity analysis

To investigate the variability of the results, a K-Means cluster analysis was performed, a technique widely used for data segmentation and classification of individuals into homogeneous groups (Bantel et al., 2013; Sipayung & Hasugian, 2025). This approach allows for the identification of groups of ecological points with similar patterns of change.

- **Data Preparation**: The input variables for the algorithm were the differences ("After" - "Before") in the generation of the five types of waste (bags, straws, breakfast bottles, water/soda bottles, food containers) for each ecological point. Given that the variables had heterogeneous units and scales, the data were standardized (transformed to Z-scores) prior to analysis (Sipayung & Hasugian, 2025; Luo, 2026). This step is crucial to ensure that all variables contribute equally to the distance calculation in the clustering.
- **Determination of the number of clusters**: The Elbow Method was used to identify the optimal number of clusters (k = 3) (Sipayung & Hasugian, 2025; Luo, 2026; Bertilsson & Remle, 2018).
- **Visualization**: Principal Component Analysis (PCA) (Zhang & Srinivasan, 2021; Seblos et al., 2023; Análisis exploratorio por Componentes Principales y Clúster, 2025; IBM, 2025) was employed on the standardized data to visualize the separation of the clusters on a two-dimensional scatter plot.

Correlation analysis

To explore the interrelationship between behavioral changes, the Spearman Rank Correlation test was used (Zhang & Srinivasan, 2021; Dalu et al., 2023; Jeon & Campbell, 2025; Mester et al., 2021), suitable for non-parametric data and ordinal scales (Zhang & Srinivasan, 2021; Chauhan et al., 2025). The association between the variation in plastic bags and the variation in each of the other four types of

waste (straws, breakfast bottles, water/soda bottles, and food containers) was evaluated across the 28 ecological points.

Finally, the patterns identified in the clusters were interpreted considering the context and qualitative observations collected in the different zones of the campus during the intervention period. The full raw data used for the analysis are provided in Online Resource 1 (Table S2).

Results

Overall impact of the intervention

The analysis of the overall impact of the intervention across the 28 ecological points is presented in Table 1. The application of the Wilcoxon signed-rank test for paired samples indicated that there was no statistically significant reduction in the generation of plastic bags (W = 160, p = 0.218), straws, or plastic breakfast bottles at the campus-wide level.

In contrast, a statistically significant increase was found in the mass of disposable food containers (tuppers) discarded (W = 329, p = 0.015), increasing from a median of 0.34 kg in the initial measurement to 0.53 kg in the final measurement. While this finding initially indicated a compensatory increase in disposable containers, the underlying behavioral mechanism is further clarified in the correlation analysis (Section 3.3).

Table 1
Results of the Wilcoxon test for the variation in plastic waste generation before and after the intervention (n = 28).

Residue Type	Median "Before"	Median "After"	W Statistic	p-value	Result (α = 0.05)
Plastic bags (units/day)	117.00	106.00	160.0	0.218	Not Significant
Straws (units/day)	8.00	10.00	208.5	0.648	Not Significant
Breakfast plastic bottles (units/day)	17.00	24.00	249.0	0.152	Not Significant
Beverage bottles (units/day)	34.00	33.00	121.0	0.038	Statistically Significant
Tuppers (kg/day)	0.34	0.57	329.0	0.015	Statistically Significant

Heterogeneity Analysis: Implementation Patterns

To investigate the variability in the response to the intervention, K-Means cluster analysis was applied. The choice of the optimal number of clusters (k = 3) was determined using the Elbow Method, the results of which are presented in Fig. 4. Once the algorithm was applied, three distinct and statistically separable groups were identified among the 28 ecological points.

These clusters represent different patterns of change in plastic waste generation observed at the ecological point level. The quantitative characterization of each cluster, based on the average variation ("After" - "Before") of each waste type, is detailed in Table 2.

To contextualize these patterns, Table 3 presents the assignment of each ecological point (PE) to its corresponding cluster, along with its main location within the campus (Faculty or administrative area).

Figure 5 visualizes the clear separation of these three clusters in a two-dimensional space using Principal Component Analysis (PCA), where each point represents a labeled ecological point.

As observed in Fig. 5 and detailed in Table 3, the clusters group ecological points with distinct behaviors:

- **Cluster 1 ('Moderate Improvement', n = 13)**: The largest group, shown in red, represents EPs with mixed results (slight reductions in some items, increases in others). These points were distributed across diverse areas, including FIM, Central Pavilion, FIGMM, FIQT, Central Library, FC, FIIS, FIP, and FIA.
- **Cluster 2 ('Successful Points', n = 7)**: Shown in green, this group aggregates PEs that experienced a significant reduction in most types of plastic waste. These points were located near main entrances (Gates 4 and 5) and in areas associated with the faculties of Architecture (FAUA), Chemical Engineering (FIQT), Central Library, Environmental Engineering (FIA), and Civil Engineering (FIC).
- **Cluster 3 ('Critical Points', n = 8)**: Visualized in blue, this group aggregates PEs where a generalized increase in the generation of most types of plastic waste was observed (see Table 2). These points were predominantly located in areas associated with the faculties of Mechanical Engineering (FIM), Electrical Engineering (FIEE), the Central Pavilion, and the Medical Center.

Table 2
Quantitative characterization of implementation clusters according to the average change in waste (After - Before).

		Average Change in Waste Generation				
Cluster Profile	n	Plastic bags	Straws	Breakfast plastic bottles	Beverage bottles	Tuppers (kg)
Cluster 1: Moderate Improvement	13	-10.2	-1.5	1.4	-8.5	0.3
Cluster 2: Successful Points	7	-116.0	-4.6	-8.9	-44.3	-0.3
Cluster 3: Critical Points	8	67.4	8.8	20.1	13.5	1.4
Notes: n: Number of ecological points belonging to each cluster.						

Values (+): Indicate an average increase in the generation of that residue.

Values (-): Indicate an average decrease in the generation of that residue.

Table 3
Cluster assignment and main location of each EP on campus.

No.	Ecological Point (EP)	Main Location (Faculty/Area)	Assigned Cluster
1	PE1	FIM	1 (Moderate)
2	PE2	FIM	3 (Critical)
3	PE3	Gate 3	3 (Critical)
4	PE4	FIM	3 (Critical)
5	PE5	Central Pavilion	1 (Moderate)
6	PE9	Gate 4	2 (Successful)
7	PE10	Central Pavilion	1 (Moderate)
8	PE11	FIGMM	1 (Moderate)
9	PE12	Central Library	3 (Critical)
10	PE14	FAUA	2 (Successful)
11	PE15	FIA	1 (Moderate)
12	PE16	FIM	3 (Critical)
13	PE18	FIQT	1 (Moderate)
14	PE21	FIQT	2 (Successful)
15	PE22	FIGMM	1 (Moderate)
16	PE23	Central Library	1 (Moderate)
17	PE25	Central Library	2 (Successful)
18	PE26	Gate 5	2 (Successful)
19	PE27	FC	1 (Moderate)
20	PE28	FIIS	1 (Moderate)
21	PE35	FIIS	2 (Successful)
22	PE39	FC	1 (Moderate)
23	PE40	FIP	1 (Moderate)
24	PE41	FIEE	3 (Critical)
25	PE42	FIA	1 (Moderate)
26	PE43	Central Pavilion	3 (Critical)
27	PE44	Medical Center	3 (Critical)

No.	Ecological Point (EP)	Main Location (Faculty/Area)	Assigned Cluster
28	PE45	FIC	2 (Successful)

Correlation analysis of changes in plastic waste

To investigate whether changes in plastic bag usage were related to changes in other plastics, Spearman correlations were calculated. The results, presented in Fig. 6, show a consistent and notable pattern: positive and statistically significant correlations were found between the variation in plastic bags and the variation in all other analyzed waste types (straws, beverage bottles, breakfast bottles, and food containers). These results indicate a comprehensive coherent behavioral response rather than a substitution effect. This effect had already been presented in previous contexts such as the COVID-19 pandemic (Jayasinghe et al., 2022; Krawczyk et al., 2024).

The strongest association was observed with food containers ($\rho = 0.678$, $p < 0.001$) and beverage bottles ($\rho = 0.662$, $p < 0.001$), followed by straws ($\rho = 0.570$, $p = 0.002$) and breakfast bottles ($\rho = 0.497$, $p = 0.007$). These results indicate that ecological points where plastic bag generation decreased also tended to experience a decrease in other plastics, and vice versa. This pattern suggests a coherent behavioral response to the comprehensive intervention, rather than a substitution effect between waste types. In other words, sub-communities tended to either adopt or reject the sustainability message in a generalized manner for all plastic products included in the dissemination campaign.

Discussion

Principal findings and interpretation

The results of this study reveal a complex narrative regarding the implementation of plastic reduction policies in institutional settings. The finding that there was no statistically significant global reduction in plastic bag generation should not be interpreted as an intrinsic failure of the regulatory policy itself, but rather as a direct consequence of the limitations of the implemented intervention, which lacked rigorous enforcement mechanisms, thus responding to the objective of evaluating efficacy in a low-governance context. Conversely, this average result suggests that the response to the intervention varied considerably across different campus areas, a heterogeneity that the cluster analysis successfully highlighted. The findings of the present research indicate that the efficacy of an intervention based on dissemination and non-sanctioning monitoring is extremely dependent on the reality and commitment of each faculty, as well as preexisting systemic barriers. Although ecological points are freely accessible, the waste patterns observed in them evidence a correlation with the dynamics and degree of commitment prevailing in neighboring faculties and offices.

Cluster 2 ('Successful Points', n = 7) demonstrates that, in certain campus areas, the intervention was sufficient to catalyze positive change in areas with greater collaboration. This success, observed in PEs associated with faculties such as FIC and FAUA (see Table 3), where greater collaboration for talks and

visible commitment were documented, aligns with the effectiveness that voluntary interventions have shown (Truelove et al., 2023; Sustainability Online, 2025). Cluster 1 ('Moderate Improvement', n = 13), which includes PEs in zones like FIIS, FC, and FIP, represents partial compliance, reflected by administrative-level support (dean's office) that did not fully translate into change by all concessionaires and users in those areas. On the other hand, Cluster 3 ('Critical Points', n = 8), with PEs located predominantly near FIM, FIEE, and the Central Pavilion, represents a clear case of implementation barriers. Specifically, systemic obstacles were identified such as the absence of environmental clauses in current contracts, lack of basic infrastructure (washing points) necessitating the use of disposables for hygiene, and economic resistance from vendors facing the higher cost of alternative packaging. The increase in waste in these zones directly correlates with these field observations, added to a high demand for takeout food and low visible commitment from local authorities. This scenario reflects that poor compliance and lack of enforcement drastically limit the success of plastic bans (Milbreta et al., 2025; Seblos et al., 2023; Heyde & Butcher, 2024). The observed dynamics, where some concessionaires complied while others did not, generated unequal competition that ultimately discouraged generalized change.

The coherent behavioral response: A novel finding

A particularly significant finding of this study was the pattern revealed by the correlation analysis. Contrary to the initial expectation of a "substitution effect" (Taylor, 2018; Macintosh et al., 2020; Berman & Johnson, 2015), positive and statistically significant correlations were found between the variation of plastic bags and all other analyzed waste types (Fig. 6). Given that the educational intervention covered all types of plastics, this result suggests a coherent behavioral response. This means that the different campus sub-communities tended to adopt or reject the sustainability message holistically for all products, rather than substituting one bad habit for another.

This coherent response is clearly manifested through the three identified clusters. Cluster 2 ('Successful Points') represents the groups that adopted the integral message. In PEs such as PE14 (FAUA), the notable reduction in bags was accompanied by a reduction in food containers, reflecting the high cooperation observed in that faculty. Conversely, Cluster 3 ('Critical Points') exemplifies the coherent rejection of the policy. PEs in FIM (such as PE2, PE4, PE16) showed considerable increases in both bags and food containers, which correlates with the observed barriers: symbolic enforcement, concessionaire resistance, and low interest from authorities. This scenario validates the critical importance of governance; without effective enforcement, compliance is left at the mercy of individual will, generating a gap between attitude and actual action (Milbreta et al., 2025; Sustainability Online, 2025; Heyde & Butcher, 2024). Previous studies explain that motivation alone is insufficient if physical opportunity (adequate infrastructure) and capacity (practical knowledge) are not guaranteed (Sustainability Online, 2025; Van Hau et al., 2025).

All mentioned factors (impossibility of applying sanctions, concessionaires without contracts, lack of incentives, uncommitted authorities) evidence systemic barriers that limited the intervention (Muposhi et al., 2022). This research empirically validates that stakeholder engagement and effective governance are

more determinant than the regulation itself (Milbreta et al., 2025). The lack of effective enforcement mechanisms left the decision to comply entirely to the will of each sub-community, originating coherent but heterogeneous responses.

Limitations

Finally, limitations must be noted: this is a single case study and the intervention period was short; furthermore, the registration of new students each semester can complicate intervention perspectives, which is why this analysis should be conducted over the long term. However, the depth of the contextual analysis and the identification of implementation patterns offer valuable lessons. Future research should explore long-term impacts and evaluate interventions that include economic incentives (Ali et al., 2021).

Conclusions

This article addresses the efficacy of plastic reduction policies in complex institutional settings, a key challenge in global waste management. Specifically, the effectiveness of an intervention based on dissemination and non-sanctioning monitoring, applied on a university campus in Peru, was evaluated. The results did not show a statistically significant relationship between this specific intervention and a generalized reduction in plastic waste. On the contrary, efficacy was strongly influenced by implementation barriers and local context, leading to the identification of three heterogeneous response patterns: success, partial compliance, and failure.

The findings of this study highlight key considerations for policymakers. First, they demonstrate that policies lacking robust enforcement and sanction mechanisms, and/or failing to achieve effective awareness and engagement across the entire community, have limited efficacy and can generate unintended consequences, such as the increase of certain types of plastics. The evidence of a coherent behavioral response suggests that comprehensive interventions provoke a radical adoption or rejection of the message. Second, cluster analysis reveals itself as a powerful diagnostic tool to identify "critical points" and "successful points" requiring differentiated strategies. Therefore, it is concluded that a one-size-fits-all approach is insufficient; to achieve comprehensive change, future waste management policies must combine clear regulations with tangible incentives, effective governance, and a structured, continuous plan for both enforcement and awareness adapted to the different actors.

Declarations

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Ethics Approval

Not applicable. This study involved the characterization of waste aggregates and did not involve human participants or animals.

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Author Contribution

C. Curi: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft. N. Requena: Validation, Investigation, Writing - review & editing. All authors read and approved the final manuscript.

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Data Availability

The datasets generated during and/or analyzed during the current study are available in the Supplementary Material and Electronic Supplementary Material files.

References

1. Ali S, Ahmed W, Solangi YA, Sharif CI, Zarei N (2021) Strategic analysis of the single-use plastic ban policy for environmental sustainability: the case of Pakistan. Clean Technol Environ Policy 23:2287–2301
2. Alternatives to single-use plastics in food packaging and production (2025) Available online: https://www.food.gov.uk/research/innovative-regulator/alternatives-to-single-use-plastics-in-food-packaging-and-production?print=1. Accessed 27 Dec 2025
3. Amir-ud-Din R, Khan M, Atif RM, Khalid S (2024) The paradox of plastic bag legislation: How bans and taxes affect PM2.5 air pollution in 208 countries. Heliyon 10:e40641

4. Bantel J, Krumsiek J, Theis FJ (2013) Statistical methods for the analysis of high-throughput metabolomics data. Comp Struct Biotechnol J 4:e201301009
5. Berman ER, Johnson RK (2015) The unintended consequences of changes in beverage options and the removal of bottled water on a university campus. Am J Public Health 105:1404–1408
6. Bertilsson CP, Remle C (2018) Corporate recycling behavior through the lens of situational factors. Master Thesis, Blekinge Institute of Technology, Karlskrona, Sweden
7. Bócoli PFJ, Gomes VEdS, Maia AAD, Marangoni Júnior L (2025) Perspectives on eco-friendly food packaging: Challenges, solutions, and trends. Foods 14:3062
8. Botella P, Baena-Morales S, García-Taibo O, Ferriz-Valero A (2022) Effects of self-construction of materials on the ecological awareness of physical education primary school students. Int J Environ Res Public Health 19:14176
9. Chauhan BVS, Berg MJ, Sharma A, Smallbone KL, Wyche KP (2025) Temporal and machine learning-based principal component and clustering analysis of VOCs and their role in urban air pollution and ozone formation. Atmosphere 16:724
10. Convery F, McDonnell S, Ferreira S (2007) The most popular tax in Europe? Lessons from the Irish plastic bags levy. Environ Resour Econ 38:1–11
11. Dalu MTB, Ngobeni BS, Dalu T (2023) Assessing pro-environmental behaviour towards plastics among staff and students at a South African university. Sustainability 15:16904
12. Edimer (2025) Análisis exploratorio por Componentes Principales y Clúster. Available online: https://edimer.github.io/Stat/6_MetodosExploratorios.html. Accessed 26 Dec 2025
13. Foolmaun RK, Chamilall DS, Munhurrun G, Sookun A (2021) Was Mauritius really successful in banning plastic carry bags, after promulgation of the regulation prohibiting plastic bags usage? Environ Dev Sustain 23:11660–11676
14. Geiger JL, Steg L, van der Werff E, Ünal AB (2019) A meta-analysis of factors related to recycling. J Environ Psychol 64:78–97
15. He G, Yu T (2023) Evaluating the Benefits and Potential of “Plastic Reduction”: A Case Study of College Students in Western China. Sustainability 15:16807
16. Heyde KV, Butcher S (2024) Investigating students' perceptions of single-use plastics at the University of the Witwatersrand, South Africa. S Afr Geogr J 106:1-21
17. IBM (2025) ¿Qué es el análisis de componentes principales (PCA)? Available online: https://www.ibm.com/es-es/think/topics/principal-component-analysis. Accessed 26 Dec 2025
18. Individual actions more effective than legislation in reducing use of single-use plastics (2025) Sustainability Online. Available online: https://sustainabilityonline.net/news/individual-actions-more-effective-than-legislation-in-reducing-use-of-single-use-plastics/. Accessed 27 Dec 2025
19. Jayasinghe RR, Abeyrathna WP, Lythgoe D, Hendawitharana MP, Liyanage CL, Williams KS, Halwatura RU (2022) Analysis of the community behavioural patterns in management of household plastic waste due to the COVID-19 pandemic in Sri Lanka. Case Stud Chem Environ Eng 6:100246

20. Jeon C, Campbell D (2025) Exploring preference heterogeneity and acceptability for forest restoration policies: Latent class choice modeling and principal component analysis. Forests 16:1507
21. Krawczyk A, Goc A, Pellegrini A, Jaguszewska N, Olivos Salas B, Bukowski M, Grodzińska-Jurczak M (2024) Journalists in a circular economy: Stakeholders' engagement in the media discourse on single-use plastics during the COVID-19 pandemic. Heliyon 10:e36299
22. Luo Y (2026) Machine learning in economic forecasting: Integrating traditional methods with a tunable LSTM. Int J Intell Sci 16
23. Macintosh A, Simpson A, Neeman T, Dickson K (2020) Plastic bag bans: Lessons from the Australian Capital Territory. Resour Conserv Recycl 154:104638
24. Mester T, Szabó G, Balla D (2021) Assessment of shallow groundwater purification processes after the construction of a municipal sewerage network. Water 13:1946
25. Milbreta U, Milich L, Andze L, Gusca J (2025) Some countries can say “No!” to single-use plastics, others cannot: Why do seemingly similar policies have different outcomes? J Sustain Res 7:e250004
26. Muposhi A, Mpinganjira M, Wait M (2022) Considerations, benefits and unintended consequences of banning plastic shopping bags for environmental sustainability: A systematic literature review. Waste Manag Res 40:248–261
27. Oludoye OO, Supakata N (2024) Breaking the plastic habit: Drivers of single-use plastic reduction among Thai university students. PLoS ONE 19:e0299877
28. Omondi I, Asari M (2021) A study on consumer awareness and behavior concerning the plastic bag ban in Kenya. J Mater Cycles Waste Manag 23:425–435
29. Panorama de políticas para plásticos en América Latina y el Caribe (2025) Available online: https://www.no-burn.org/wp-content/uploads/2025/10/Panorama-de-politicas-para-plasticos-en-America-Latina-y-el-Caribe.pdf. Accessed 27 Dec 2025
30. Papp A, Oremus K (2025) Plastic bag bans and fees reduce harmful bag litter on shorelines. Science (In Press)
31. Seblos K, Sangcap C, Tabañag D, Tapdasan FD, Ocampo CN, Paño JD (2023) Challenges and initiatives on single-use plastics in universities: A meta synthesis. J Soc Sci 4:2360–2379
32. Sipayung S, Hasugian PM (2025) Integration of PCA and K-Means clustering for staple food segmentation in support of national food policy. SinkrOn 9:3175–3189
33. Taylor RLC (2018) Bag leakage: The effect of disposable carryout bag regulations on unregulated bags. University of Sydney School of Economics, Sydney
34. Truelove HB, Largo-Wight E, Siuda ANS, Gowans S, Minichiello H, Hill J (2023) Reducing single-use plastic on college campuses: Theory of Planned Behavior-based brief interventions. Curr Res Ecol Soc Psychol 4:100098

35. Universidad Nacional de Ingeniería (2019) Resolución Rectoral N° 1788: Aprobar la Directiva N° 010-2019-DIGA/UNI. Lima, Peru
36. Universidad Nacional de Ingeniería (2025) Estadísticas de Estudiantes. Available online: https://dirce.uni.edu.pe/estadistica/alumnos. Accessed 25 Dec 2025
37. Van Hau P, Robertson K, Thyne M, Hamlin R, Rundle-Thiele S (2025) Reducing single-use plastics (SUPs) consumption: A synthesis of I and S level approaches. Sustainable Futures 10:101087
38. Wang W, Wang J, Wu D (2022) The optimal strategy of China's plastic drinking straws ban based on consumer heterogeneity and retailer competition. Sustainability 14:745
39. Wilcoxon F (1945) Individual comparisons by ranking methods. Biometrics Bull 1:80–83
40. Yang Z, Kim S (2019) An agent-based model of plastic bag ban. In: Karwowski W, Ahram T (eds) IHSI 2019. Springer, Cham, vol 903, pp 478–483
41. Yang Z, Kim S (2020) Diffusion of environmental protectionism: Single-use plastic bag ban policy in California. Springer, Cham
42. Zhang H, Srinivasan R (2021) A biplot-based PCA approach to study the relations between indoor and outdoor air pollutants using case study buildings. Buildings 11:218
43. Zulfa V, Nugraheni PL (2020) Effectiveness of community empowerment in waste management program to create sustainable tourism in Karawang, West Java. IOP Conf Ser Earth Environ Sci 485:012087

Figures



Figure 1

A Ecological Point

B Green container

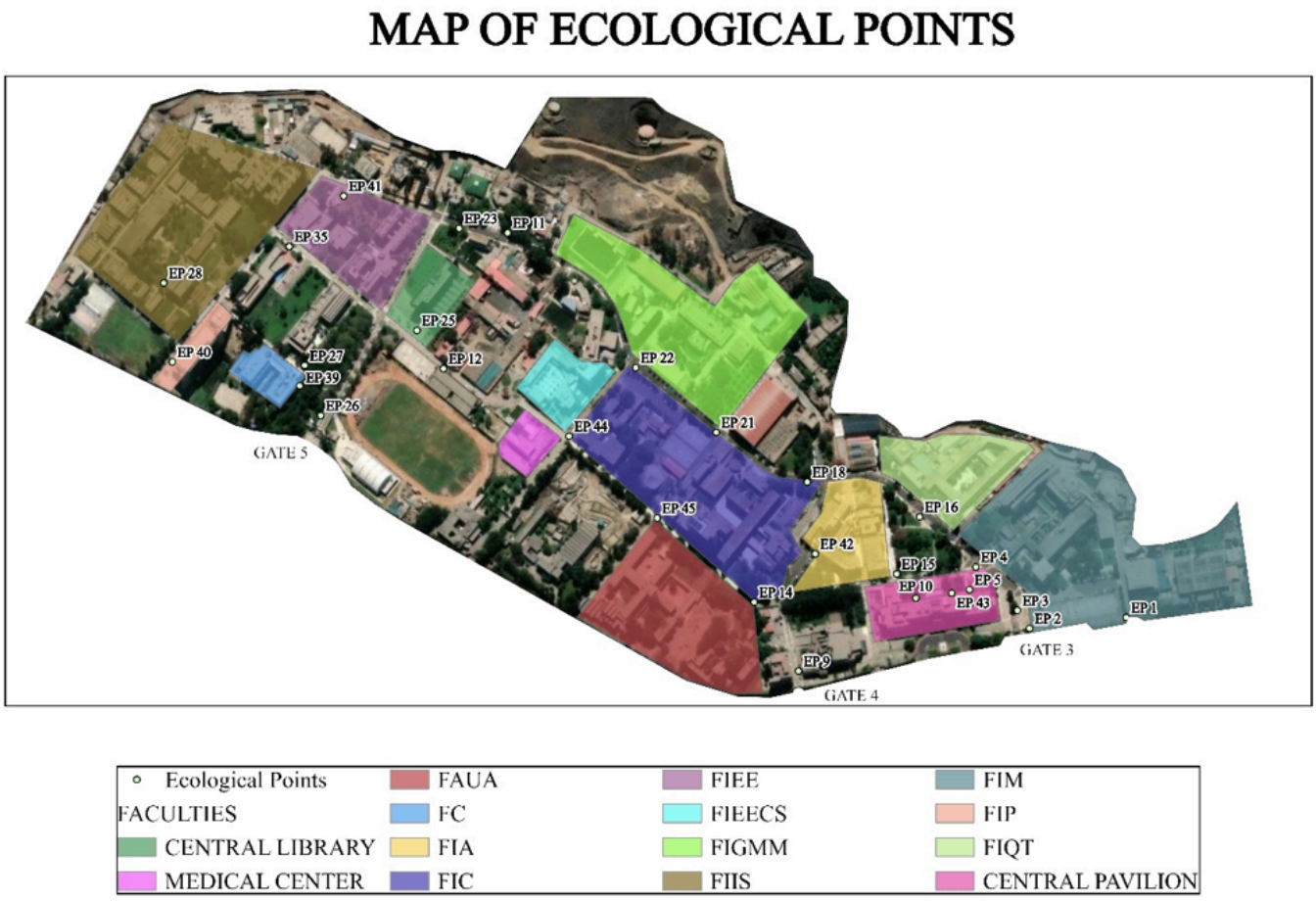


Figure 2

Map of ecological points

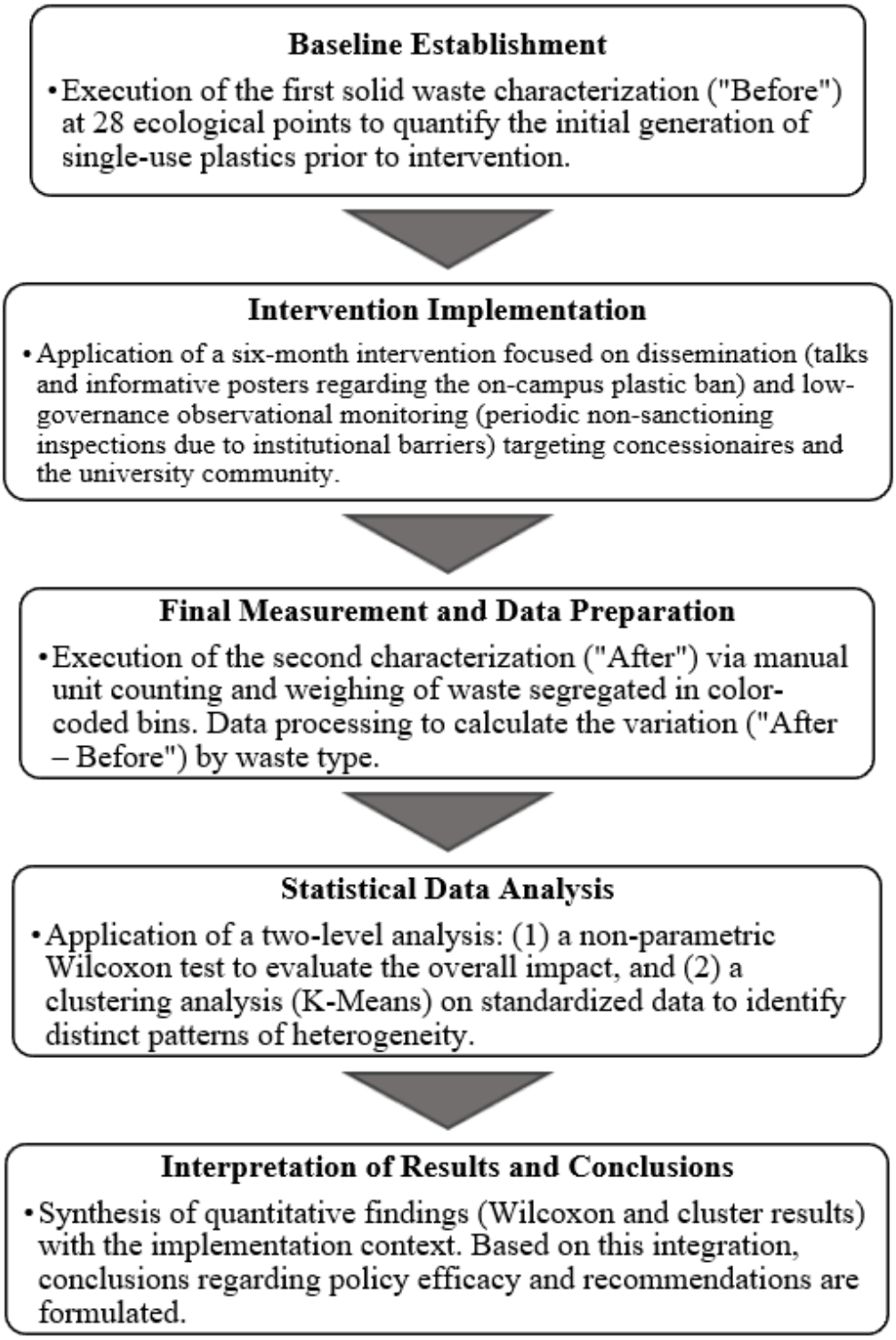


Figure 3

Summary of the steps, methods, and results of the study.

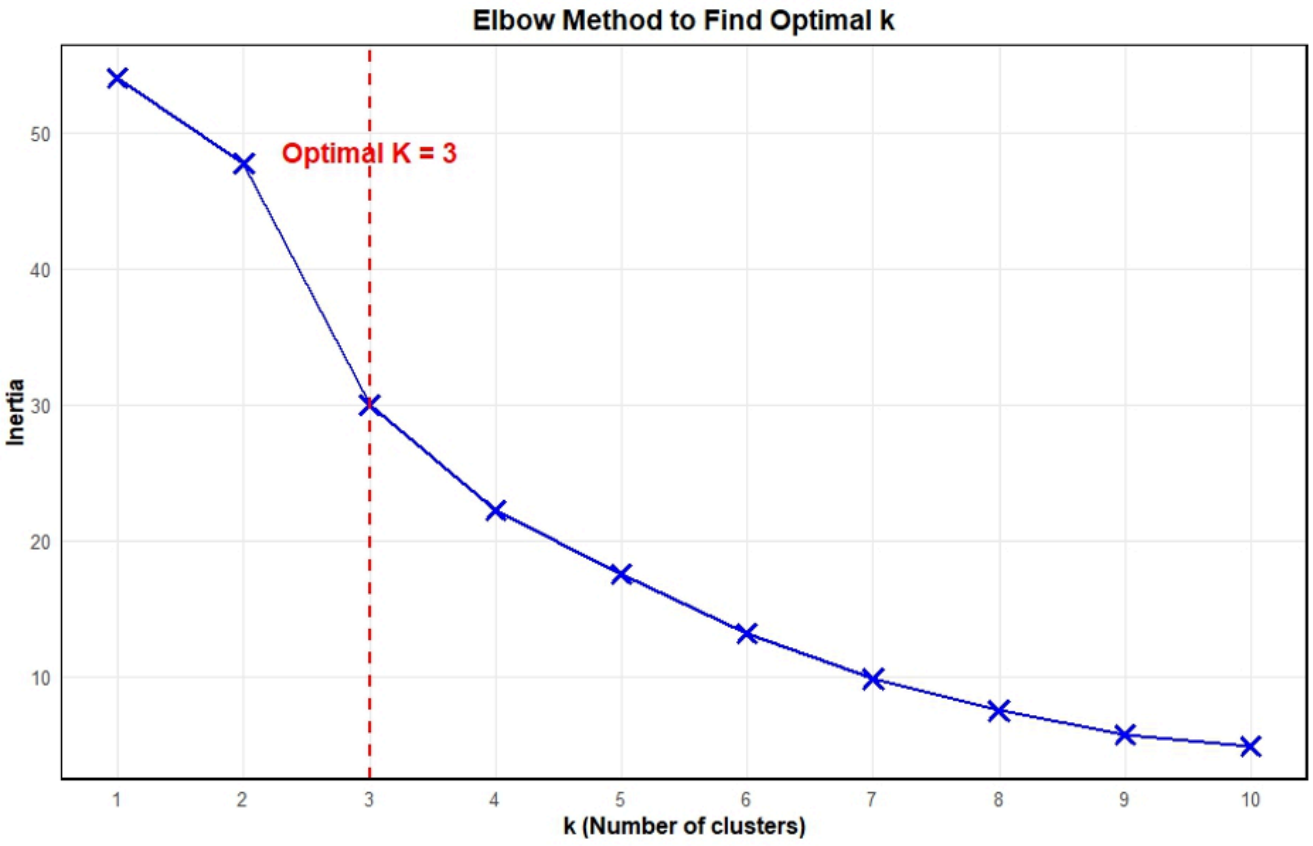


Figure 4

Visualization of the optimal number of clusters using the Elbow Method.

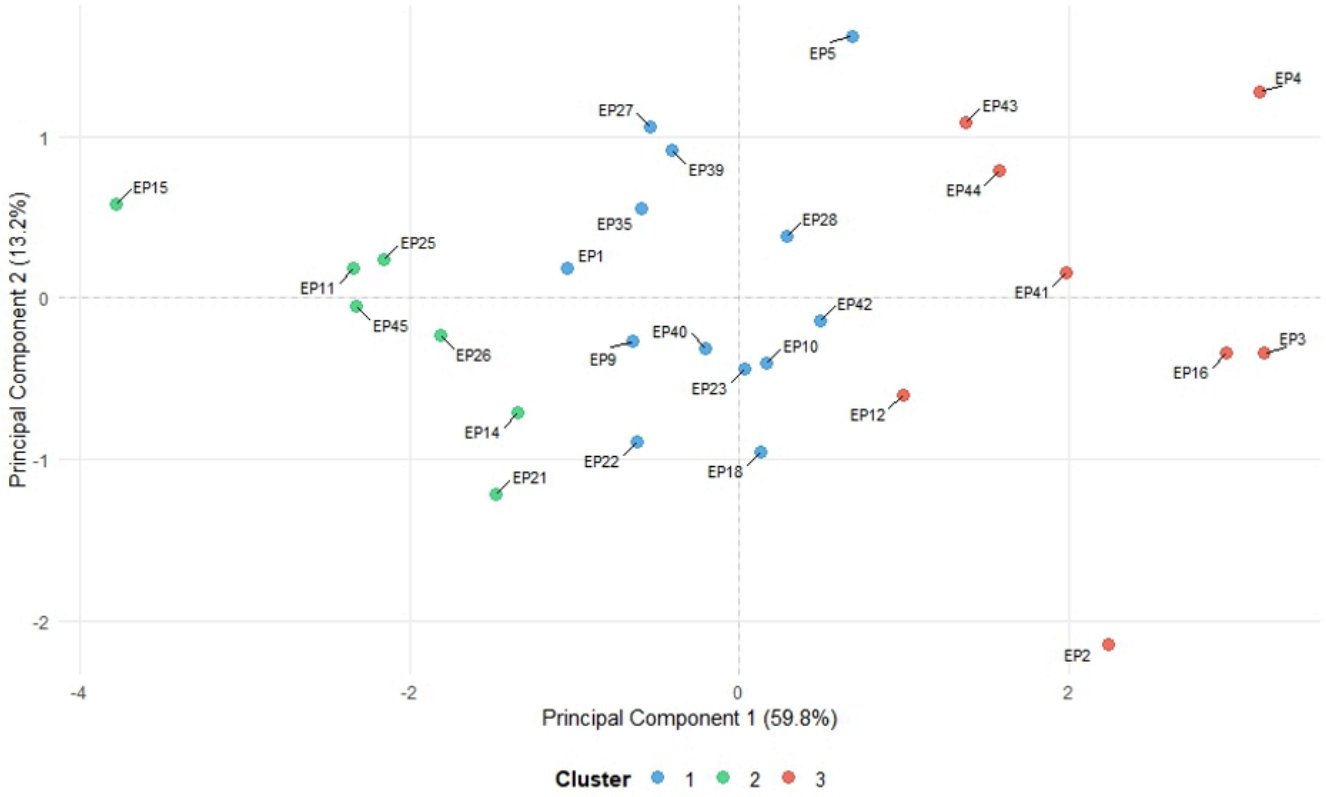


Figure 5

Visualization of the three implementation clusters using Principal Component Analysis (PCA).



Figure 6

Spearman Rank Correlation between the variation of Plastic Bags and other characterized plastics.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- ESM1.docx
- ESM2.xlsx