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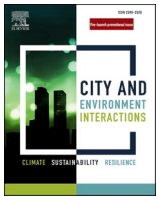

Research Articles

Perceptions of waste valorization and hazardousness: A methodological approach based on ordinal proximity measures

Rodion Iurev [a,b], José Luis García-Lapresta [b], Pedro Antonio García-Encina [c,d], Silvia Bolado [c,d], María Molinos-Senante [c,d,*]

[a] ITMO University, Kronverksky Pr. 49, bldg. A, St. Petersburg, 197101, Russia
[b] PRESAD Research Group, Departamento de Economía Aplicada, Universidad de Valladolid, Spain
[c] Institute of Sustainable Processes, Universidad de Valladolid, Valladolid, Spain
[d] Chemical Engineering and Environmental Technology Department, Universidad de Valladolid, Valladolid, Spain

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ABSTRACT

Citizens play a crucial role in achieving circular economy and sustainable waste management. This study introduces a novel methodological framework to assess public perceptions of potential waste valorization and hazardousness. Utilizing ordinal proximity measures, the framework also explores how individuals perceive qualitative scales used in these assessments. A case study involving 175 participants, including waste management experts and engineering students, was conducted to elucidate perceptual differences between these groups across 14 types of waste. It was found that 45% and 62% of respondents did not perceive the scales of waste valorization and hazardousness as uniform. Both groups identified glass as the most valuable and pharmaceutical waste as the least valuable. However, perceptions varied considerably for other wastes depending on the respondents' expertise. Cereal straw and batteries were perceived as the least and most hazardous wastes, respectively, by both students and experts, with paint exhibiting the greatest variance in perceived hazardousness between the two groups.

Introduction

Waste management intersects with numerous social and economic areas, influencing a wide range of global challenges, including health, climate change, poverty alleviation, resource security, and the promotion of sustainable production and consumption practices [34]. It is closely linked to the Sustainable Development Goals (SDGs), and its principles are directly or indirectly reflected in more than half of the 17 goals, underscoring its critical role in the global sustainability agenda [26]. The significance of effective and sustainable waste management practices is gaining ground among decision-makers at local, national, and international levels. Thus, the revised Waste Framework Directive (2018/851/EU) mandates that European households and businesses must recycle at least 55 % of their municipal solid waste by 2025 and 65 % by 2035. Furthermore, by 2035, only up to 10 % of the total generated municipal waste will be permitted to be landfilled [6]. The adoption of the European Circular Economy Action Plan in 2020 marks a significant advance, positioning the circular economy as a key component of the European Union's (EU) industrial strategy and emphasizing its importance as a development priority for the EU [23].

While much attention has been placed on the production aspect of the shift from a linear to a circular economy [27,8,25], the consumer behavior aspect is equally critical for advancing a circular economy and enhancing sustainable waste management practices [5,24,16]. Consequently, previous studies have been conducted to assess consumer perceptions of the circular economy in general and its specific aspects, including consumption patterns, various energy forms, clothing reuse, extending the lifespan of household appliances, and food-related behaviors [11,28,4]. Given the adverse impacts of improper waste management on public health and the environment, understanding citizens' perceptions of waste hazardousness is also crucial. To this end, a body of research has emerged, focusing on the risk perception associated with specific waste types, such as refrigerators, household appliances, and mobile phones [21,32,7]. This research is vital for developing strategies that align with public perceptions and concerns, ultimately facilitating more effective and participatory waste management and circular economy initiatives.

* Corresponding author.
E-mail address: maria.molinos@uva.es (M. Molinos-Senante).

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Literature review

While previous research on citizens' perceptions of the circular economy and waste hazardousness has significantly contributed to understanding the public's role in enhancing waste management, they present two key limitations. Firstly, these studies have focused only on solid waste management, yet "waste" encompasses a broader spectrum, including undesirable outputs from human activities in the form of gases, liquids, and solids, impacting air, water, and land [30]. A more comprehensive approach that includes perceptions of liquid and gaseous waste, alongside solids, would offer a more holistic understanding of public perceptions, aiding more informed decision-making. Secondly, from a methodological point of view, previous research often conducted surveys using the Likert scale, where respondents rank their perceptions on an ordered numerical scale [19]. However, this method can be problematic if respondents perceive varying distances between scale points, making the conversion of qualitative terms to numerical values potentially misleading. Such discrepancies can affect the outcomes, particularly when individual assessments are aggregated, as different encodings of the same qualitative scale could yield divergent results [12]. This issue is relevant when gauging public perceptions of waste valorization potential and hazardousness, where precise quantitative and qualitative scales for these metrics are lacking. Addressing these limitations could enhance the accuracy and reliability of research in this field, providing clearer insights of public attitudes and perceptions regarding waste management in the context of a circular economy.

Most methods dealing with non-uniform ordered qualitative scales in ordinal form handle linguistic terms through cardinal approaches or fuzzy techniques as in Herrera et al. [17] and Martínez and Herrera [20] which are practically equivalent to using numerical values and do not make sense in the context of non-uniform ordered qualitative scales [12]. By contrast, García-Lapresta and Pérez-Román [14] proposed ordinal proximity measures in the setting of non-uniform qualitative scales by comparing the proximities between linguistic terms without numbers, in a pure ordinal way. This methodological approach is based on making pairwise comparisons of psychological proximities between the terms of the scales. Then, the pairs of terms can be ranked according to their ordinal proximities. This methodological approach might be useful to identify people's perception regarding potential waste valorization and waste hazardousness where quantitative scales are not available.

The literature review reveals two main research gaps. First, there is a limited focus on assessing public perceptions of waste management within the framework of a circular economy. Existing studies have predominantly concentrated on citizens' perceptions of solid waste management, while largely neglecting liquid and gaseous waste streams, which are essential components of waste within a circular economy framework. Second, from a methodological standpoint, previous research primarily relies on Likert-scale surveys, which may introduce biases due to the non-uniform psychological distances between scale points. This study addresses both gaps by broadening the research scope to encompass all waste streams—solid, liquid, and gaseous—and by employing ordinal proximity measures to enhance the reliability of public perception assessments regarding waste hazardousness and valorization.

The study aims to achieve three primary objectives. Firstly, it seeks to evaluate public perceptions of a selected set of wastes—solid, liquid, and gaseous—in terms of their potential for valorization and hazardousness. Secondly, it aims to explore how individuals perceive the proximity between pairs of terms on two proposed qualitative scales: one measuring potential waste valorization and the other assessing perceived waste hazardousness. Thirdly, this research compares perceptions between experts in waste management and non-experts such as engineering students. By achieving these objectives, this research makes several significant contributions to the literature. Methodologically, it pioneers the exploration of individuals' perceptions of proximity among the terms in an ordered qualitative scale. This approach is novel in that it employed interactive elements (sliders) in the survey, enabling respondents to indicate their perceived distances between the linguistic terms of the scale. In terms of waste management, it is the first to apply ordinal proximities in ordered qualitative scales to assess and rank a variety of wastes based on their potential for valorization and perceived hazardousness.

The transition from a linear to a circular economy is a global priority. International organizations like the EU and the United Nations have made circular economy principles a central component of their sustainability strategies, particularly through frameworks like the Sustainable Development Goals. A more comprehensive understanding of public perceptions across all types of waste is essential for developing inclusive and holistic waste management strategies on a global scale. In this context, the findings from this study have the potential to inform the development of educational and environmental programs, enhancing public awareness and understanding of the circular economy's scope. By expanding the focus beyond the commonly recognized domain of solid waste recycling, these programs can encourage a more comprehensive appreciation of the circular economy's potential, promoting a broader adoption of its principles and practices.

Methodology

Sample and survey definitions

The study engaged two distinct groups for its survey: experts in the field of waste management and treatment and engineering students. The inclusion of both experts and students enriches the study, providing a balanced view that encompasses both seasoned expertise and new academic learning in the field of waste management. On the one hand, the expert cohort comprised researchers from the Institute of Sustainable Processes at the University of Valladolid, Spain. They were contacted via email with a survey link between March 3, 2023, and March 15, 2023. A total of 67 responses were received and subsequently utilized for the analysis. This group's insights are particularly valuable due to their specialized knowledge and experience in sustainable processes and waste management. On the other hand, the student cohort consisted of first year engineering students from the University of Valladolid, who were surveyed in their classrooms between March 21, 2023, and March 26, 2023. In this case, 108 responses were collected. Each participant provided a total of 14 observations, corresponding to one for each type of waste, covering both risk and valorization perceptions. Overall, the study amassed 175 participants, yielding a dataset of 2,450 observations concerning waste hazardousness and 2,338 observations on potential waste valorization due to some inconsistencies identified in 112 observations.

The selection of wastes for evaluation in this study (Table 1) was strategically based on three main criteria, ensuring relevance, diversity, and manageability. Firstly, the chosen waste types were carefully selected to align with the expertise and knowledge of the participants from the Institute of Sustainable Processes. This approach ensures that the evaluation leverages the participants' specialized understanding, eliminating the risk of attributing potential differences in perceptions between experts and students to a lack of relevant expertise. Secondly, the selection encompassed a variety of waste forms, including liquid, solid, and gaseous wastes, to capture a comprehensive range of challenges associated with waste management. This diversity allows the study to address the nuances of handling different waste types. Finally, the number of waste types was intentionally limited to 14 to maintain the survey's clarity and focus. This constraint was aimed at preventing participant fatigue and ensuring meaningful engagement with the survey content, thereby enhancing the reliability of the responses.

The evaluation of the selected waste types was based on two key criteria: potential for valorization and hazardousness. These criteria were assessed using ordered qualitative scales, providing a structured

Table 1
Type of waste assessed.

Type of waste
Batteries
Cereal straw
CO_2
Computer equipment
Glass
Domestic wastewater
Magazines
Old furniture
Pharmaceutical waste
Paint
Pig slurry
Refrigerator
Tires
Used oil

and nuanced approach to evaluate characteristics and implications of each type of waste. Tables 2 and 3 show the ordered qualitative scales for waste valorization and waste hazardousness, respectively.

The questionnaire for both students and experts was on-line and did not allow users to go on the next stage if they did not answer all the questions. First, the respondents were asked to select only one answer option for rating each waste (Table 1) for each category using ordered qualitative scales (Tables 2 and 3) (the HTML radio button mechanism was used for this). After completing this stage, the respondents were asked to show their perceptions about the closeness between the terms of the scales used for evaluating the different kinds of waste through a slider. Figs. 1a and 1b contain the English versions of the sliders used to obtain the respondents' perceptions about the qualitative scales. The two extreme terms of the scales were fix and the respondents could move the intermediate terms according to their own perceptions.

Quantification of people's preference based on ordinal proximity measures

The assessment was structured into three principal stages as is shown in Fig. 2. Initially, participants were asked to rate each type of waste using ordered qualitative scales, assigning qualitative values based on their perception of potential waste valorization (Table 2) and perceived hazardousness (Table 3) for each waste category (Table 1). Following this, participants were tasked with adjusting sliders to reflect their perception of the closeness between pairs of terms on the two qualitative scales (Figs. 1a and 1b). The information provided by the places where the respondents set the terms of the scale is twofold. On the one hand it generates the numerical scores that implicitly they give to the qualitative assessments. On the other hand, we obtain, through a MATLAB program, the metrizable ordinal proximity measure that corresponds to the perceptions about the scale. This last information is purely ordinal and allows us to classify the respondents according to their ordinal perceptions about the scale. Finally, the responses from each individual were analyzed such that, considering their ratings on the qualitative scale and the proximity between terms indicated via the sliders, individual perceptions regarding the potential for waste valorization and its hazardousness were obtained. Subsequently, for the two study groups (experts and students), basic statistics parameters (mean and quartiles) were estimated.

The use of ordered qualitative scales, as the ones proposed in this study, is due to the fact that human beings are more comfortable using words rather than numbers under vague and uncertain situations [35–36,33]. Usually, individuals' opinions are imprecise, and they cannot be easily expressed by means of exact numerical values [3,31,29].

Table 2
Ordered qualitative scale used for evaluating waste's potential valorization.

l_1	l_2	l_3	l_4
Non-valuable	Limited value	Partially valuable	Easily valuable

Table 3
Ordered qualitative scale used for evaluating waste' hazardousness.

l_1	l_2	l_3	l_4	l_5
Harmless	Not very hazardous	Hazardous	Very hazardous	Extremely hazardous

Consider an ordered qualitative scale $\mathscr{L} = \{l_1, l_2, \ldots, l_g\}$, with $g \geq 2$ and $l_1 \prec l_2 \prec \cdots \prec l_g$, i.e., l_1 is the lowest term of the scale, l_2 is the next term of the scale, and so on, until l_g, that is the highest term of the scale (see Tables 2 and 3). The set of ordinal degrees of proximity is denoted by $\Delta = \{\delta_1, \delta_2, \ldots, \delta_h\}$ with $h \geq 2$. These degrees are arranged from the highest to the lowest: δ_1 is the maximum degree of proximity (or lowest psychological distance), δ_2 is the second degree of proximity, and so on, until δ_h that is the minimum degree of proximity (or highest psychological distance). It is important to note that the elements of Δ are not numbers, but ordinal degrees (the first, the second, etc.) [13].

To illustrate the notion of ordinal proximity measure, consider the 3-term ordered qualitative scale {'poor', 'fair', 'good'} ($g = 3$). Three ordinal proximity measures are possible, and they can be visualized in Fig. 3:

1. If the scale is perceived as *uniform*, i.e., the proximity between 'poor' and 'fair' is the same than the proximity between 'fair' and 'good', only three ordinal degrees of proximity are needed, i.e., $\Delta = \{\delta_1, \delta_2, \delta_3\}$: δ_1 is the proximity between each term with itself; δ_2 is the proximity between 'poor' and 'fair', and also between 'fair' and 'good'; and δ_3 is the proximity between 'poor' and 'good'.
2. If 'fair' is perceived closer to 'poor' than to 'good', then four ordinal degrees of proximity are needed, i.e., $\Delta = \{\delta_1, \delta_2, \delta_3, \delta_4\}$: δ_1 is the proximity between each term with itself; δ_2 is the proximity between 'poor' and 'fair'; δ_3 is the proximity between 'fair' and 'good'; and δ_4 is the proximity between 'poor' and 'good'.
3. Analogously, if 'fair' is perceived closer to 'good' than to 'poor', again four ordinal degrees of proximity are needed, i.e., $\Delta = \{\delta_1, \delta_2, \delta_3, \delta_4\}$: δ_1 is the proximity between each term with itself; δ_2 is the proximity between 'fair' and 'good'; δ_3 is the proximity between 'poor' and 'fair'; and δ_4 is the proximity between 'poor' and 'good'.

Obviously, when the scale has more than three terms, as in our study, the complexity increases.

If we want a slider to generate all possible metrizable proximity measures on an ordered qualitative scale, it is necessary to select an appropriate granularity of the slider for each value of g. We have considered a total granularity of $G = g!$, with a granularity between consecutive linguistic terms of $\frac{G}{g-1} = g \cdot (g-2)!$ Table 4 shows these granularities for $g = 4, 5$.

Once we know the positions where the respondents place each linguistic term of the scale on the slider, it is necessary to normalize them to obtain their corresponding scores: the position divided by G. Tables 5 and 6 show the results for the waste potential valorization and waste hazardousness scales, respectively.

Results

Perception of potential waste valorization

According to the proposed methodology, perceptions of the closeness between the terms of the waste valorization scale were obtained from the positions provided by the respondents through the sliders (Fig. 1a). From the numerical distances between the mentioned positions, it is possible to generate the ordinal proximity measures that correspond to

Fig. 1a. Slider of the scale used to evaluate waste' potential valorization.

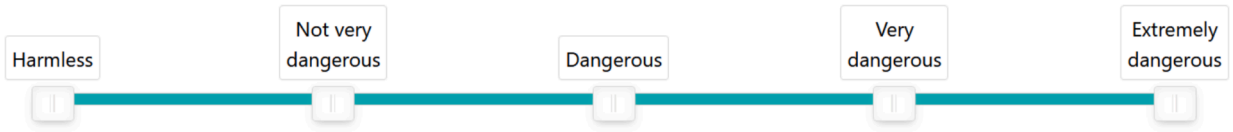

Fig. 1b. Slider of the scale used to evaluate waste' hazardousness.

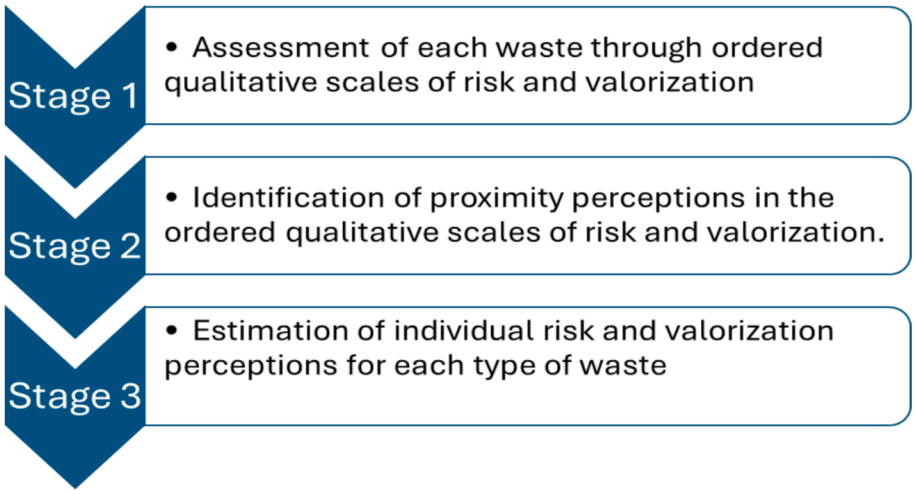

Fig. 2. Methodological steps of the study.

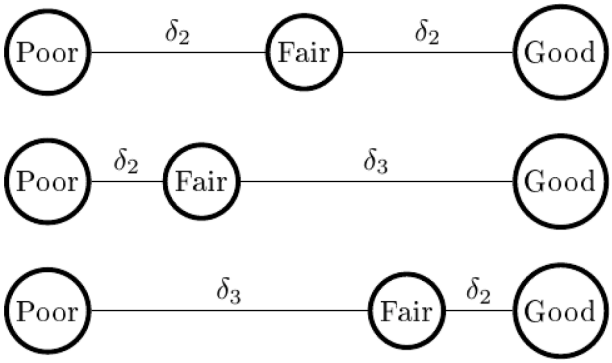

Fig. 3. Visualization for matrices A_{22}, A_{32} and A_{23}.

these perceptions by means of the algorithm proposed by García-Lapresta and Pérez-Román [15]. The findings indicate that 45 % of the participants did not perceive the scale as uniform; that is, they experienced varying psychological distances between the terms used in the scale. This figure is slightly higher in the case of students (46 %) than in experts (42 %). Fig. 4 evidences that the average values reported by both students and experts are not significantly different, despite noticeable variability observed within each respondent group for specific terms. For instance, the responses for the term "difficult to value" ranged widely, with a maximum value of 14 and a minimum of 1, highlighting that individuals interpret qualitative scales differently. There is greater dispersion among student responses compared to those from experts, which could be attributed to the larger number of student respondents and their relatively lower familiarity with the subject matter. Findings on Fig. 4 highlight the critical need to explore how respondents interpret qualitative scales prior to their application. Neglecting to do so may lead to skewed conclusions, as the assumption that all respondents perceive the scale uniformly can introduce significant biases in the data

Table 4
Granularities of the sliders for $g = 4, 5$.

g	$g \cdot (g-2)!$	$G = g!$
4	8	24
5	30	120

Table 5
From positions to scores for $g = 4$.

Linguistic terms	l_1	l_2	l_3	l_4
Positions on the slider	0	7	15	24
Scores	0	0.292	0.625	1

Table 6
From positions to scores for $g = 5$.

Linguistic terms	l_1	l_2	l_3	l_4	l_5
Positions on the slider	0	28	60	90	120
Scores	0	0.233	0.500	0.750	1

interpretation process. The metrizable ordinal proximity measures that correspond to the answers about the closeness perceptions between the four terms of the ordered qualitative scale used to evaluate the waste' valorization (Table 2) are shown as supplemental material.

Using a scale tailored to each respondent's perception, as gauged through sliders, Table 7 presents the average perceptions on waste valorization from the entire sample as well as from the sub-samples of experts and students. Fig. 5 corroborates that both groups rank glass as the most valuable waste, whereas pharmaceutical waste is perceived as the most challenging to valorize. The comparison between experts and students' perceptions reveals a significant difference in how they view used oil and CO_2 valorization (Table 7) with a divergence of 22.6 % and 21.3 %, respectively Fig. 4 illustrates this discrepancy, showing CO_2 ranked 8th by experts and dropping to 12th for students.

Overall, experts tend to view nearly all types of waste as more easily valuable than students do, except for pharmaceutical waste, batteries, paint, and computer equipment. Consequently, the average score for the potential valorization of waste is slightly higher among experts (0.613) than among students (0.553), reflecting these nuanced differences in perception based on the respondents' background and expertise. To evaluate whether the differences in waste valorization perceptions between experts and students are statistically significant, a Mann-Whitney test was conducted. The null hypothesis (H_0) involves that there is no difference between the distributions of both groups. The resulting p-value of 0.301 indicates that the differences in waste valorization perceptions are not statistically significant at the 95 % confidence level.

Fig. 5 elucidates the varying perspectives between experts and students regarding the valorization potential of different wastes, particularly highlighting the disparities in views on computer equipment and used oil. Students perceive computer equipment as relatively easier to valorize, placing it 5th in their ranking, in contrast to experts who rank it

Table 7
Average waste' potential valorization according to all sample, experts and students.

Type of waste	**Type of respondents**			
	All	Experts	Students	Students – Experts (%)
Pharmaceutical waste	0.359	0.321	0.381	6.00
Batteries	0.405	0.351	0.436	8.50
Paint	0.418	0.366	0.448	8.20
Refrigerator	0.460	0.474	0.452	−2.20
Used oil	0.506	0.649	0.423	−22.60
CO_2	0.511	0.645	0.432	−21.30
Tires	0.564	0.571	0.560	−1.10
Computer equipment	0.595	0.541	0.627	8.60
Domestic wastewater	0.616	0.732	0.548	−18.40
Pig slurry	0.648	0.728	0.601	−12.70
Old furniture	0.702	0.733	0.683	−5.00
Magazines	0.728	0.782	0.697	−8.50
Cereal straw	0.761	0.839	0.715	−12.40
Glass	0.784	0.853	0.744	−10.90
Average	**0.575**	**0.613**	**0.553**	**−6.00**

10th. This difference could be attributed to the experts' background in environmental engineering, where the focus is predominantly on valorizing liquid and solid industrial waste, whereas students may have greater familiarity with recycling electronic components. Conversely, when it comes to used oil, students are more pessimistic about its valorization prospects, ranking it 13th out of 14 waste types. In contrast, experts view used oil as more amenable to valorization, which likely reflects their exposure to and involvement in specific research and experiments related to waste valorization. This discrepancy underscores the influence of professional and academic background on perceptions of waste valorization, highlighting the importance of interdisciplinary approaches in understanding and addressing waste management challenges.

Fig. 6 presents the key statistics of waste potential valorization for both experts and students. Except for glass perception by experts, the potential valorization for all waste types ranged from a minimum of 0 to a maximum of 1 for both groups, indicating that perceptions spanned the full spectrum from non-valuable to highly valuable. This result

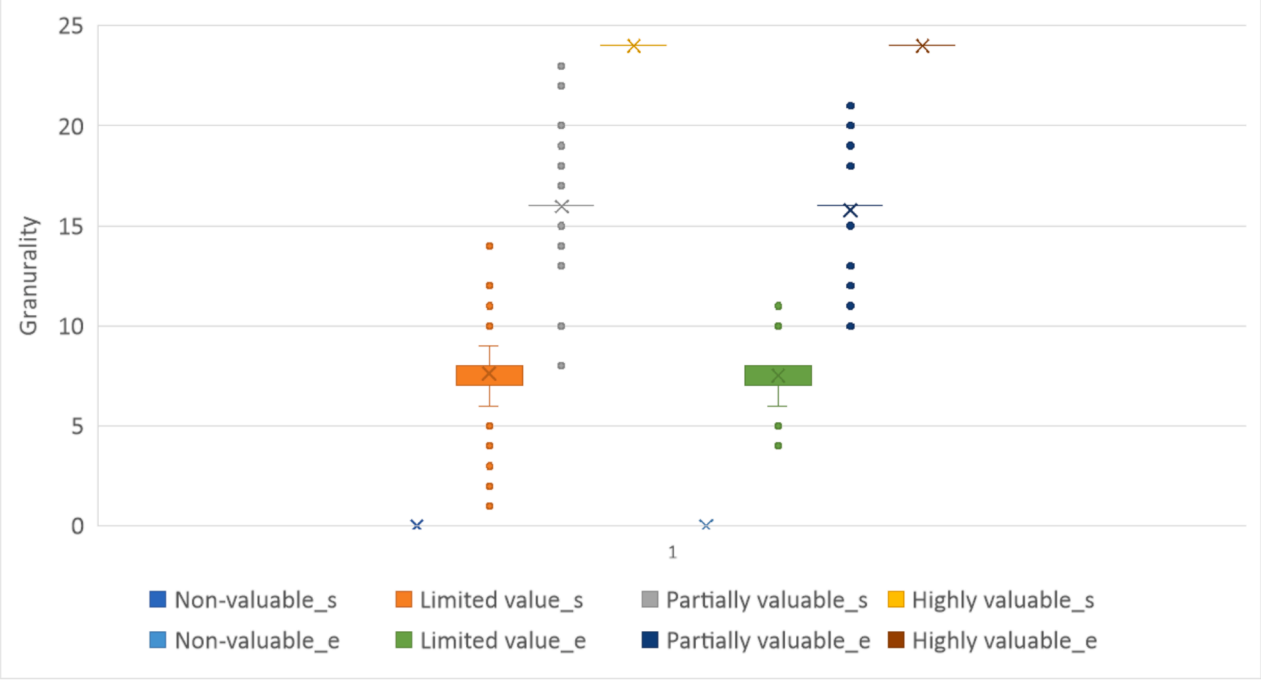

Fig. 4. Perception of waste valorization qualitative scale. The subscript "e" refers to experts and the subscript "s" refers to students.

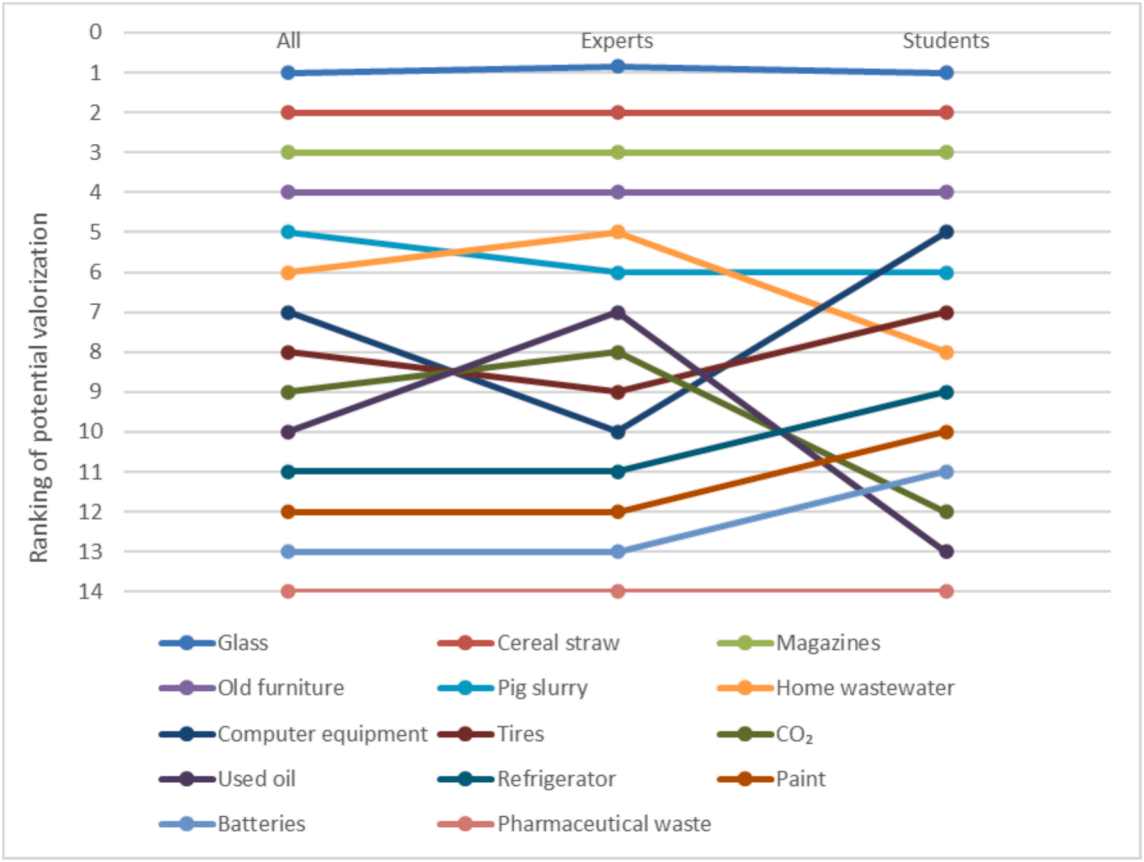

Fig. 5. Ranking of waste potential valorization according to average values for all sample, experts and students.

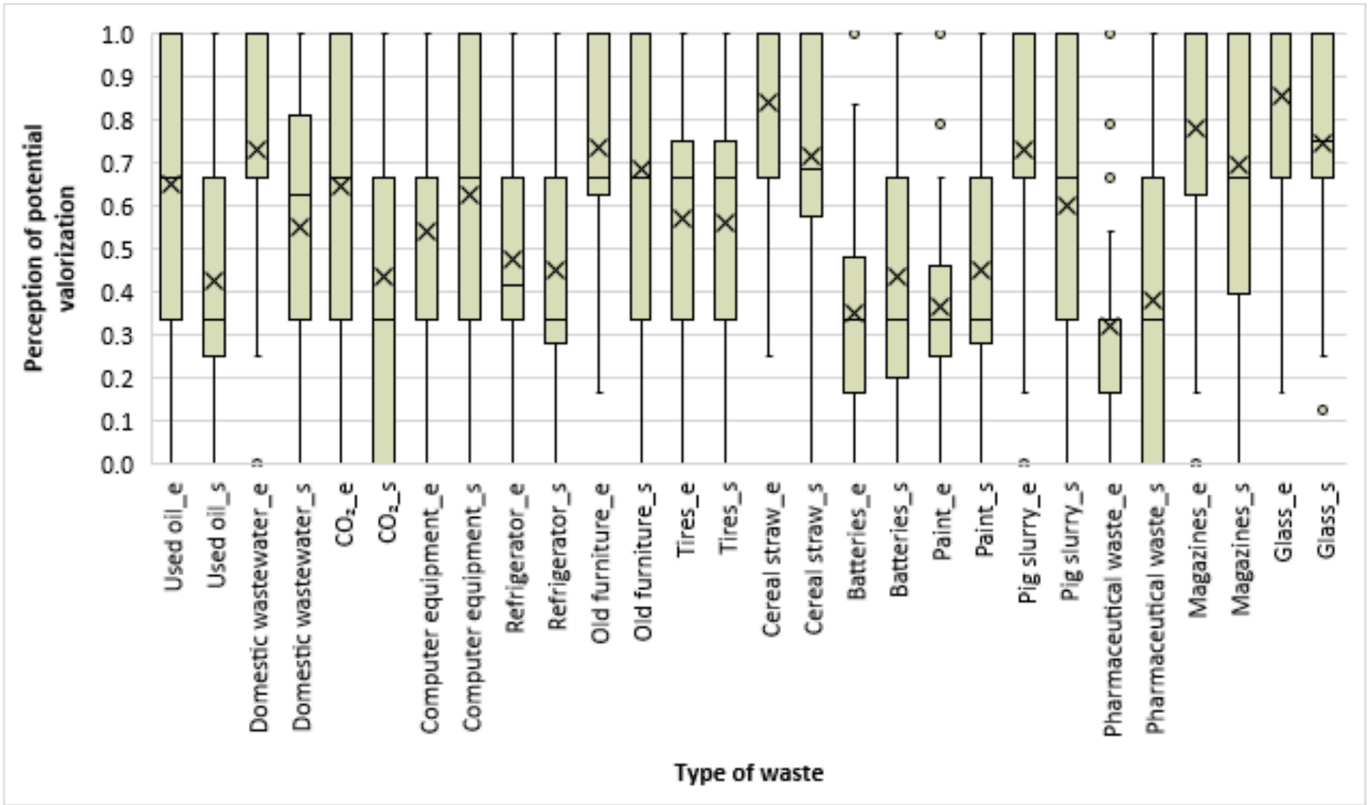

Fig. 6. Main statistics of perception of waste potential valorization. The subscript "e" refers to experts and the subscript "s" refers to students.

highlights significant variations in individual perceptions across all analyzed waste types. The variability in perception was particularly pronounced among students for CO2 and pharmaceutical waste, where the coefficients of variation[1] were estimated at 83.5 % and 85.7 %, respectively. For experts, the waste type exhibiting the greatest variability in potential valorization was batteries, with a coefficient of variation of 80.6 %. Overall, the data depicted in Fig. 6 reveals substantial divergence in student responses, possibly reflecting their relative lack of specialized knowledge compared to experts.

Perception of waste hazardousness

The investigation into people's perceptions of waste hazardousness, which utilized a scale ranging from harmless to extremely hazardous, reveals significant insights. With 62 % of respondents perceiving the scale as non-uniform, the study underscores the critical role that scale perception plays in research outcomes.[2] Differences between experts and students are in this case more pronounced perceived as 71 % of students and 46 % of experts perceived the waste hazardousness scale as non-uniform. Fig. 7 shows that, as in the case of waste valorization, the average values assigned by students and experts to each term of the qualitative scale of waste hazardousness do not differ notably. However, it is evident that students exhibit greater variability in their perception of the qualitative scale of waste hazardousness compared to experts. This diversity is particularly relevant for the term " hazardous" for which students positioned the slider between 20 and 118. This suggests that while there is general agreement on the rating scales between the two groups, students show a broader range of perceptions about what constitutes "hazardous" indicating potentially less consistency or experience in evaluating such hazardousness compared to experts.

The utilization of a non-uniform scale, adjusted based on each respondent's perception, allows Table 8 to provide a nuanced view of waste hazardousness perceptions among experts, students, and the overall sample. Cereal straw is uniformly regarded as the least hazardous waste by both experts and students, with an average score of 0.128. Conversely, batteries are perceived as the most hazardous waste, achieving a score of 0.843 for the collective sample, indicating a general consensus on its hazardousness, although students rate the hazard of batteries higher than experts do. This consensus on the extremities of the scale is interesting, particularly when cross-referenced with Table 7, which evaluates waste valorization potential. Here, cereal straw is deemed the second easiest waste to valorize, while batteries are considered among the least valuable. This inverse relationship between perceived hazardousness and valorization potential is quantitatively supported by the Pearson correlation coefficients[3]: −0.878 for the entire sample, −0.913 for experts, and −0.736 for students. These figures suggest a strong negative correlation, implying that waste perceived as more hazardous are generally considered less amenable to valorization, underscoring the intricate interplay between perceived risk and valorization potential in shaping attitudes toward waste management and recycling efforts.

Table 8 illustrates a difference in the perception of waste hazardousness between students and experts, with students on average viewing the waste as more hazardous (0.529) compared to experts (0.470). This variance likely stems from the experts' deeper knowledge and experience in waste management, which may provide a more nuanced understanding of actual risks. A significant discrepancy is noted in the perception of glass's hazardousness, where students assign it nearly double the hazard score (0.495) compared to experts (0.254). Despite the substantial divergence in hazardousness perceptions for certain types of waste, the differences between students and experts are not statistically significant at the 95 % confidence level, as indicated by the Mann-Whitney test p-value of 0.421.

The ranking of waste hazardousness in Fig. 8 highlights that the perception of paint's hazard level varies between experts and students, representing the largest positional shift among the evaluated wastes. Experts consider paint to be the 3rd most hazardous of the 14 types assessed, whereas students place it in the 6th position. This discrepancy could be attributed to the experts' more extensive knowledge about the chemical composition and potential hazards of paints. Additionally, since paint is not a typical household waste, its associated risks might not be as widely recognized or understood by the general public, including students. This gap in perception underscores the impact of specialized knowledge on evaluating the hazardousness of various waste materials and highlights the need for broader educational efforts to raise awareness about the potential risks of less common but hazardous waste like paint.

Fig. 9 delineates the variability in the perceptions of waste hazardousness among two respondent groups, students and experts. For students, the maximum value for all types of waste analyzed was 1.0, indicating that at least one respondent viewed each type of waste as extremely hazardous. Conversely, experts reported lower maximum values for certain wastes such as old furniture (0.508), cereal straw (0.750), magazines (0.750), and glass (0.750), suggesting that no expert regarded these waste types as extremely hazardous. On the lower end of the scale, both students and experts consistently rated batteries and pharmaceutical waste above 0.0, indicating a unanimous perception of these wastes as not harmless. This pattern also applied to paint (experts) and tires (students), where none of the respondents considered these wastes to be harmless. Significant variability was noted particularly with cereal straw, where the coefficient of variation was remarkably high at 127.5 % among experts and even higher at 149.5 % among students, pointing to a widely divergent perception of its hazardousness. In contrast, perceptions of pharmaceutical waste were more consistent, demonstrated by relatively low coefficients of variation of 24.4 % for experts and 28.2 % for students, indicating a more uniform assessment of its hazardousness among respondents.

Discussion

Regarding valorization perception, the results presented in Fig. 5 indicate that both experts and students regard glass as the most valuable waste. In contrast, pharmaceutical waste is perceived as the most difficult to valorize. This perception likely reflects the prevalent recycling practices in Spain, where glass recycling rates stand at 70.1 % [9], with glass container recycling being an early initiative in Spanish urban areas [10]. Conversely, despite the existence of the "Sigre" model in Spain, which facilitates pharmaceutical waste collection at pharmacies and includes energy recovery from non-hazardous waste, public perception still views pharmaceutical waste valorization as particularly difficult. Nevertheless, the fact that this waste type received scores above zero indicates that while people find it challenging to valorize, they do not consider it an impossible task. As Gonella et al. [16] discuss, psychological barriers and social influence play a significant role in the adoption of circular economy practices, including waste valorization. In Spain, the separate collection of glass for recycling is a well-established social norm, which explains its high perceived valorization by the public. In contrast, the valorization of pharmaceutical waste appears to be hindered by psychological barriers, suggesting that perceptions of risk, safety concerns, or lack of awareness may negatively influence people's willingness to engage in pharmaceutical waste recycling. In

[1] $Coefficientofvariation = \frac{Standarddeviation}{Average}$.

[2] The results for the metrizable ordinal proximity measures that correspond to the answers about the closeness perceptions between the five terms of the ordered qualitative scale used to evaluate the waste' hazardousness is shown in supplemental material.

[3] $Pearsoncorrelationcoefficient = \frac{cov(X,Y)}{\sigma_X \sigma_y}$ where $cov(X, Y)$ is the covariance of the variables (X, Y), σ_X is the standard deviation of X and, σ_y is the standard deviation of Y.

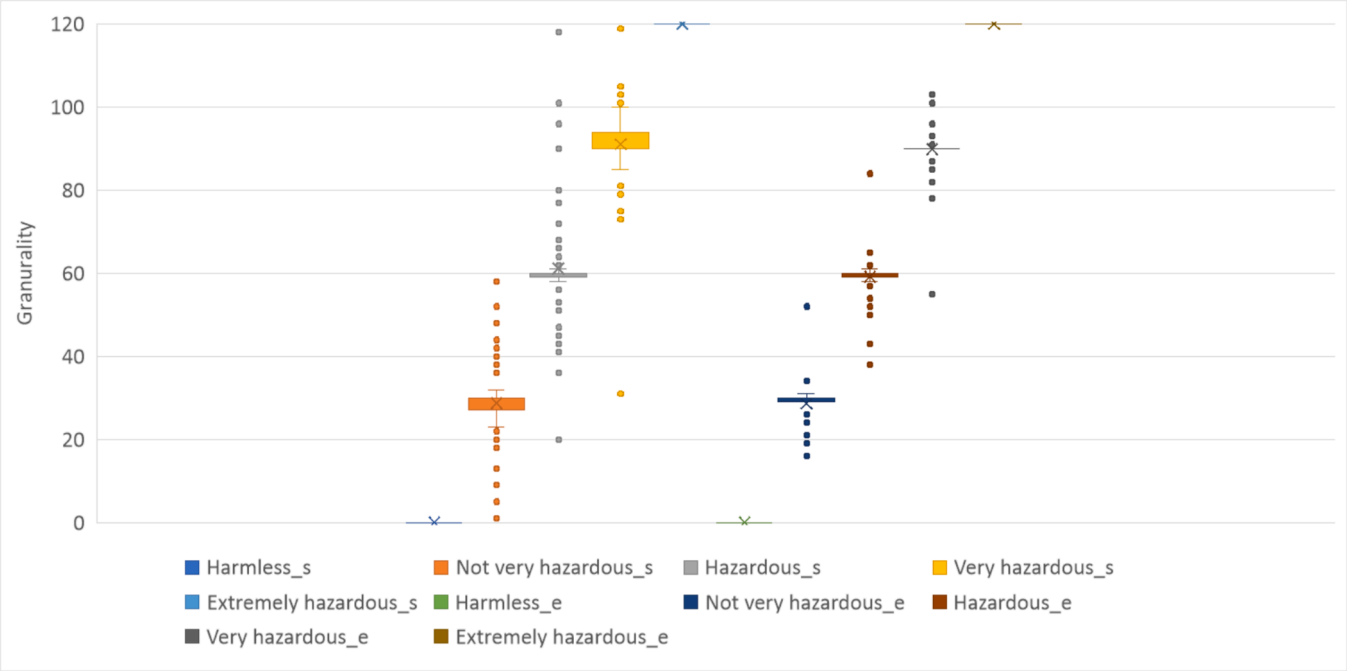

Fig. 7. Perception of the waste hazardousness qualitative scale. The subscript "e" refers to experts and the subscript "s" refers to students.

Table 8
Average waste' hazardousness according to all sample, experts and students.

Type of waste	Type of respondents			
	All	Experts	Students	Students – Experts (%)
Cereal straw	0.128	0.139	0.120	−1.9
Old furniture	0.217	0.188	0.234	4.6
Magazines	0.230	0.148	0.281	13.3
Pig slurry	0.366	0.434	0.324	−11
Domestic wastewater	0.398	0.425	0.381	−4.4
Glass	0.402	0.254	0.495	24.1
CO_2	0.563	0.492	0.607	11.5
Used oil	0.591	0.538	0.624	8.6
Refrigerator	0.625	0.547	0.674	12.7
Computer equipment	0.631	0.550	0.680	13
Paint	0.636	0.650	0.627	−2.3
Tires	0.686	0.610	0.733	12.3
Pharmaceutical waste	0.780	0.804	0.765	−3.9
Batteries	0.843	0.803	0.868	6.5
Average	**0.507**	**0.470**	**0.529**	**5.9**

contrast to the perception of glass and pharmaceutical waste, a significant divergence exists between experts and students regarding the valorization of used oil and CO_2. This variation may stem from the fact that several experts involved in the study are engaged in research on converting CO_2 into valuable substances like hydroxyectoine and ectoine, influencing their perception of CO_2 as more readily valuable compared to the students' viewpoint. Overall, experts tend to view nearly all types of waste as more easily valuable than students do, except for pharmaceutical waste, batteries, paint, and computer equipment. This is because the group of experts have not developed neither studies nor technologies to valorize this set of wastes.

The influence of educational background, both general and specific to waste management, on waste valorization perception has been well-documented in previous research. Matsumoto et al. [22] compared consumer perceptions of remanufactured auto parts in the United States and Japan, concluding that Japanese consumers had lower awareness of remanufactured products, which led to a higher perception of risk. Similar findings were reported by Chang et al. [7] in the context of mobile phone waste, where a relationship was identified between environmental concern, risk perception, and recycling intention. Furthermore, Wang et al. [32] found that educational level, along with gender and place of residence, significantly influenced e-waste valorization perception and the final disposal decision at the product's end-of-life. In a more specific study on refrigeration equipment, Martinho et al. [21] concluded that Portuguese, French, and Spanish consumers with a higher perception of climate change risks exhibited more positive attitudes and behaviors toward climate-friendly actions, including waste valorization. Additionally, environmental concerns not only influence valorization perceptions but also have a measurable impact on separate waste-collection rates [24], highlighting the importance of educational campaigns in achieving the ambitious waste recycling targets set by the European Union's Directive 2018/850/EC.

When focusing on the perception of waste hazardousness, both students and experts identified batteries as the most hazardous and cereal straw as the least hazardous waste. This perception is largely influenced by general knowledge about waste risks. Batteries are widely recognized to contain toxic heavy metals that can harm human health and the environment if not handled properly. Additionally, recent incidents, including fires and explosions involving consumer electronics and electric vehicles, have been widely reported in the media, further amplifying public awareness and concerns about the hazards associated with batteries. In contrast, cereal straw is perceived as low-hazard waste due to its natural composition. Straw is commonly used for applications such as animal bedding, mulch, and soil amendment—practices well-known among students and experts in Valladolid (Spain), where the survey was conducted. These applications are not associated with significant hazards, contributing to a perception of safety. Furthermore, in Valladolid, cereal straw is a familiar and widely generated waste, reinforcing its association with low hazardousness due to its common and non-threatening uses.

Findings from our study are consistent with previous research. Brennan et al. [4], based on a survey of 965 Australian consumers, found that food waste—an organic waste similar to cereal straw—is not perceived as a major environmental issue. Similar conclusions were drawn by Sousa et al. [28] in a study of 422 Portuguese respondents, where awareness of the potential environmental impacts of food waste was found to be relatively low. In contrast, Atlason et al. [2], in a survey

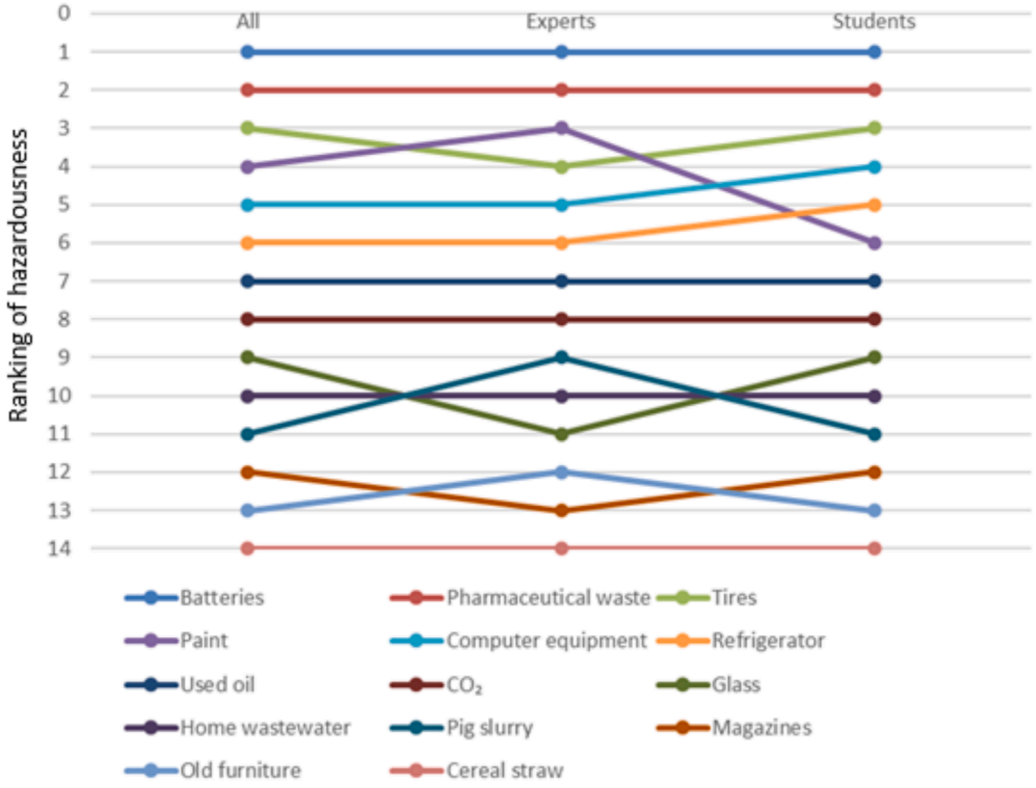

Fig. 8. Ranking of waste hazardousness according to average estimated values for all sample, experts and students.

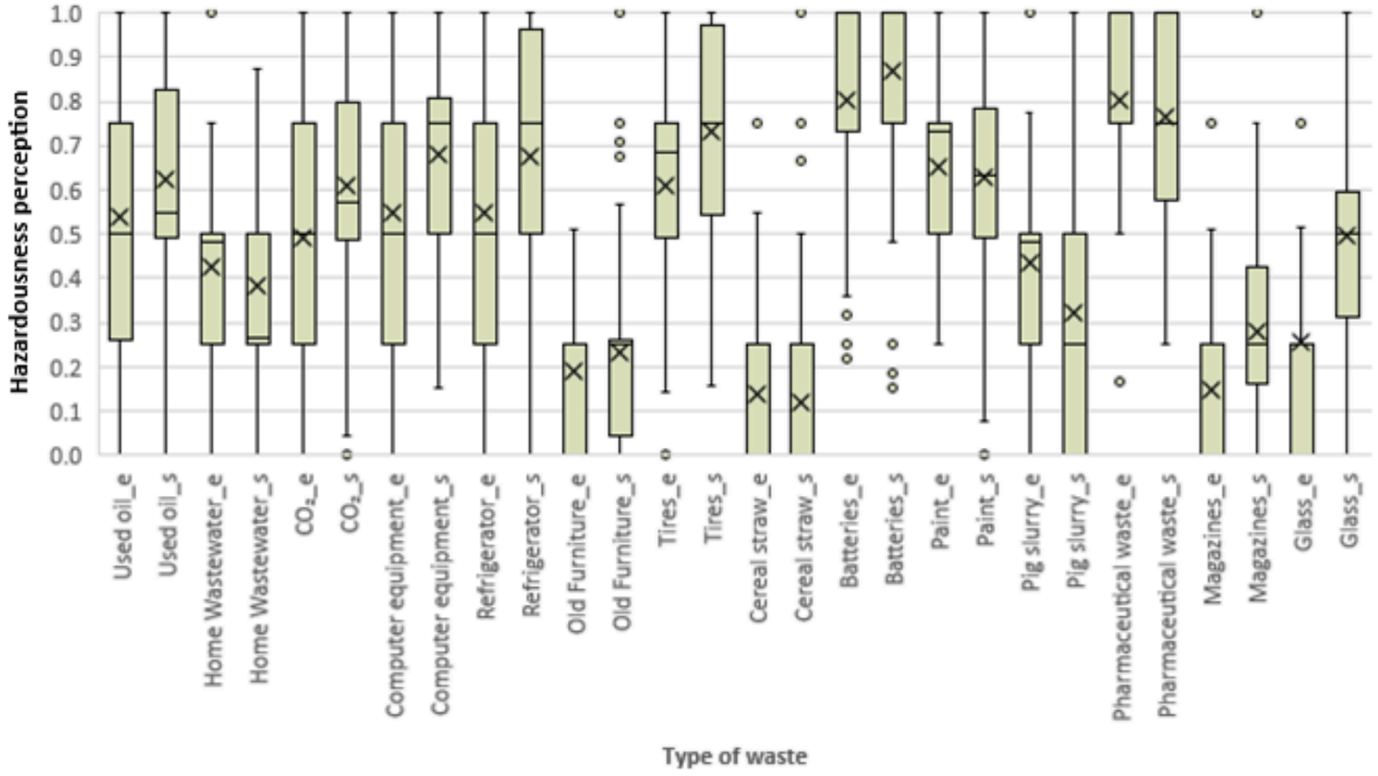

Fig. 9. Main statistics of perception of waste hazardousness. The subscript "e" refers to experts and the subscript "s" refers to students.

of 146 Danish participants, concluded that reuse is the preferred end-of-life option for electrical and electronic appliances, rather than their valorization. This aligns with our findings, which indicate that both students and experts perceive computer equipment and batteries as challenging to valorize. The findings of this study have relevant policy implications for promoting sustainable waste management practices

within the framework of a circular economy. Given the observed differences between experts and non-experts (students) regarding the potential valorization and hazardousness of specific waste types, policymakers should develop strategies that actively engage citizens in waste management initiatives by addressing existing knowledge gaps. Public engagement campaigns should focus on increasing awareness of the benefits of waste valorization and clarifying the risks associated with various types of waste to encourage greater participation in circular economy practices. In this context, risk communication strategies should be tailored to different audience groups, taking into account the non-uniform perception of qualitative scales. For instance, educational programs targeting non-experts should emphasize the safe handling and potential reuse of waste types perceived as hazardous. Additionally, the study highlights a strong inverse correlation between perceived hazardousness and valorization potential, suggesting that waste perceived as more hazardous is less likely to be considered for reuse. This finding underscores the need for an integrated policy approach that simultaneously addresses both waste valorization potential and perceived hazardousness. Waste management policies should avoid addressing these aspects in isolation and instead adopt a holistic framework that promotes the safe and efficient recovery of valuable resources from waste while mitigating environmental and health risks. Such an approach would contribute to the successful implementation of circular economy principles in waste management systems.

Motivation and opportunities are key reinforcing factors that promote pro-environmental behaviors, contributing to improved waste management [21]. Regarding motivations, individuals must be aware of and recognize the importance of proper waste management. Traditional approaches to raising awareness include educational campaigns in schools, high schools, and universities, as well as public outreach initiatives for community engagement. However, alternative and more innovative strategies can also be developed. For instance, mobile applications could be designed to educate users on waste segregation, recycling, and the risks associated with improper waste disposal. Utilizing social media platforms to raise awareness and promote sustainable waste practices can be an effective and engaging strategy, particularly for young audiences. This could be further complemented by virtual reality experiences, illustrating the environmental impact of improper waste management practices. In terms of opportunities, behavioral facilitators are essential for enabling sustainable waste management practices. Several potential approaches include: (i) the implementation of labels on packaging and electronic devices to help consumers easily identify waste risks and valorization potential; (ii) the adoption of green labeling, promoting eco-friendly products with certified waste-conscious labeling; (iii) ensuring accessible and efficient waste disposal systems that facilitate waste valorization; and (iv) implementing behavioral nudge policies to enhance sustainable waste management practices. Nudging strategies have proven effective in reducing food waste among consumers, often resulting in significant reductions [18]. Examples of nudge interventions include email reminders prompting individuals to adopt sustainable behaviors and providing feedback on past waste-related behaviors, increasing awareness of their impact [1].

Conclusions

Consumer behavior and citizen attitudes are crucial for progressing towards a circular economy and sustainable waste management. However, existing scales for measuring perceptions of potential waste valorization and waste hazardousness are qualitative, which hinders the understanding of citizens' perceptions on these topics. To address this challenge, this study introduces a novel methodological approach based on ordinal proximity measures which additionally enables the exploration of how individuals perceive both qualitative scales. The case study analyzed a set of 14 types of waste and involved a sample of 175 participants, including waste management experts and engineering students, to elucidate differences in perceptions between these two groups.

Focusing on the qualitative scales for waste valorization and perceived hazardousness, 45 % and 62 % of respondents, respectively, did not perceive them as uniform. This high variability in perceptions emphasizes the necessity of ensuring that scales used in surveys are interpreted consistently by respondents to avoid skewed data and erroneous conclusions. The findings demonstrate that without a clear and common understanding of scale gradations, the reliability of research findings can be compromised, stressing the need for careful scale design and validation in research methodologies to accurately capture public perceptions and attitudes.

Both students and experts ranked glass and pharmaceutical waste as the most and least valuable, respectively. However, significant differences were observed in the valuation of other wastes, such as CO_2 and computer equipment, where perceptions varied based on the respondents' knowledge. A similar pattern emerged in perceptions of waste hazardousness; cereal straw and batteries were perceived as the least and most hazardous waste, respectively, for both students and experts. In contrast, perceptions of paint's hazardousness showed the greatest divergence between them. This indicates that knowledge and familiarity with specific types of waste significantly influence perceptions of value and risk. Moreover, a negative correlation between perceived hazardousness and valorization were evidenced. The findings suggest that waste management policies should adopt a holistic approach, integrating considerations of waste valorization and hazardous waste management rather than addressing these issues in isolation.

While this study makes notable contributions to the literature on risk perception and waste valorization, it is not without limitations, which offer potential areas for future development. One key limitation is the static nature of the methodological approach, as the survey design does not allow for iterative responses or adaptive questioning based on participant input, resulting in missed opportunities for follow-up questions or deeper exploration of perceptions. In this context, it may be valuable to repeat the survey with students after they have completed courses on waste management and treatment to identify whether their perceptions have changed. Additionally, the study is based on a relatively small sample of 175 participants and specific respondent groups, which limits the generalizability of the findings to broader, more diverse populations. Future studies should aim to include larger and more diverse samples to enhance the generalizability of the results. Furthermore, the analysis was confined to 14 types of waste, providing depth but limiting breadth and excluding other significant categories. Expanding the study to include more waste types, such as emerging hazardous and electronic wastes, would improve its relevance to global waste management challenges.

CRediT authorship contribution statement

Rodion Iurev: Software, Methodology. **José Luis García-Lapresta:** Writing – original draft, Funding acquisition, Formal analysis, Conceptualization. **Pedro Antonio García-Encina:** Writing – review & editing, Supervision, Conceptualization. **Silvia Bolado:** Writing – review & editing, Formal analysis, Conceptualization. **María Molinos-Senante:** Writing – original draft, Visualization, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cacint.2025.100193.

Data availability

Data will be made available on request.

References

[1] Antonschmidt H, Lund-Durlacher D. Stimulating food waste reduction behaviour among hotel guests through context manipulation. J Clean Prod 2021;329:129709.
[2] Atlason RS, Giacalone D, Parajuly K. Product design in the circular economy: Users' perception of end-of-life scenarios for electrical and electronic appliances. J Clean Prod 2017;168:1059–69.
[3] Beyth-Marom R. How probable is probable? A numerical translation of verbal probability expressions. J Forecast 1982;1:257–69.
[4] Brennan L, Francis C, Jenkins EL, Schivinski B, Jackson M, Florence E, et al. Consumer perceptions of food packaging in its role in fighting food waste. Sustainability 2023;15(3):1917.
[5] Camacho-Otero J, Boks C, Pettersen IN. Consumption in the circular economy: a literature review. Sustainability 2018;10(8):2758.
[6] Chachami-Chalioti S-E, Emmanouil C, Latinopoulos D, Kungolos A. Circular economy aspects of the new national solid waste management plan and citizens' engagement in northern Greece. Circ Econ Sustain 2024;4(3):2011–30.
[7] Chang Y-S, Yue Z, Qureshi M, Rasheed MI, Wu S, Peng M-Y-P. Residents' waste mobile recycling planned behavior model: the role of environmental concern and risk perception. Int J Emerg Mark 2023;18(12):6388–406.
[8] Diaz A, Baumgartner RJ. A managerial approach to product planning for a circular economy: strategy implementation and evaluation support. J Clean Prod 2024;442:140829.
[9] Ecovidrio (2024a). Data on glass recycling in Spain. Available at: https://www.ecovidrio.es/resultados-reciclaje-vidrio-2023.
[10] Ecovidrio (2024b). History of glass recycling in Spain. Available at: https://www.ecovidrio.es/asi-funciona-el-sistema/un-poco-de-historia.
[11] European Commission (2018). Behavioural Study on Consumers' Engagement in the Circular Economy. Available at: https://op.europa.eu/en/publication-detail/-/publication/5de64de7-f9d3-11e8-a96d-01aa75ed71a1/language-en.
[12] García-Lapresta JL, González del Pozo R. An ordinal multi-criteria decision-making procedure under imprecise linguistic assessments. Eur J Oper Res 2019;279(1):159–67.
[13] García-Lapresta JL, González del Pozo R, Pérez-Román D. Metrizable ordinal proximity measures and their aggregation. Inf Sci 2018;448–449:149–63.
[14] García-Lapresta JL, Pérez-Román D. Ordinal proximity measures in the context of unbalanced qualitative scales and some applications to consensus and clustering. Appl Soft Comput 2015;35:864–72.
[15] García-Lapresta, J.L., Pérez-Román, D. (2020). Eliciting proximities between terms of ordered qualitative scales. *IEEE 10th International Conference on Intelligent Systems (IS)*, Sofia, Bulgaria, pp. 294-298, doi: 10.1109/IS48319.2020.9200159.
[16] Gonella JDSL, Godinho Filho M, Ganga GMD, Latan H, Chiappetta Jabbour CJ. A behavioral perspective on circular economy awareness: the moderating role of social influence and psychological barriers. J Clean Prod 2024;441:141062.
[17] Herrera F, Herrera-Viedma E, Martínez L. A fuzzy linguistic methodology to deal with unbalanced linguistic term sets. IEEE Trans Fuzzy Syst 2008;16(2):354–70.
[18] Liechti C, Mack G, Ammann J. A systematic literature review of impactful food waste interventions at the consumer level. Sustain Prod Consumption 2024;52:552–65.
[19] Likert R. A technique for the measurement of attitudes. Arch Psychol 1932;22(140):1–55.
[20] Martínez L, Herrera F. An overview on the 2-tuple linguistic model for computing with words in decision making: extensions, applications and challenges. Inf Sci 2012;207:1–18.
[21] Martinho G, Castro PJ, Santos P, Alves A, Araújo JMM, Pereiro AB. Environmental behaviours and risk perception of domestic consumers: refrigeration equipment case study. Cleaner Prod Lett 2022;3:100024.
[22] Matsumoto M, Chinen K, Endo H. Comparison of U.S. and Japanese consumers' perceptions of remanufactured auto parts. J Ind Ecol 2017;21(4):966–79.
[23] Mazur-Wierzbicka E. Circular economy: advancement of European Union countries. Environ Sci Eur 2021;33(1):111.
[24] Romano G, Lombardi GV, Rapposelli A, Gastaldi M. The factors affecting Italian provinces' separate waste-collection rates: an empirical investigation. Waste Manag 2022;139:217–26.
[25] Saha K, Dey PK, Kumar V. A comprehensive review of circular economy research in the textile and clothing industry. J Clean Prod 2024;444:141252.
[26] Sharma, H.R., Bhardwaj, B., Sharma, B., Kaushik, C.P. (2021). Sustainable solid waste management in India: Practices, challenges and the way forward. In: Kaushik, A., Kaushik, C.P., Attri, S.D. (eds), *Climate Resilience and Environmental Sustainability Approaches*, pp. 319-349.
[27] Sijtsema SJ, Snoek HM, van Haaster-de Winter MA, Dagevos H. Let's talk about circular economy: a qualitative exploration of consumer perceptions. Sustainability 2020;12(1):286.
[28] Sousa PM, Moreira MJ, de Moura AP, Lima RC, Cunha LM. Consumer perception of the circular economy concept applied to the food domain: an exploratory approach. Sustainability 2021;13(20):11340.
[29] Teigen KH. The language of uncertainty. Acta Psychol 1988;68:27–38.
[30] UNEP and ISWA (2015). Global Waste Management Outlook. Available at: https://www.miteco.gob.es/content/dam/miteco/images/es/resanalisisgestionpnumaiswa_tcm30-178826.pdf.
[31] Wallsten TS, Fillenbaum S, Cox JA. Base rate effects on the interpretations of probability and frequency expressions. J Mem Lang 1986;25:571–87.
[32] Wang F, Liu Q, Yin X. Exploring influencing factors of consumers' wasted household appliances disposal behavior considering product heterogeneity in China. J Clean Prod 2023;418:138065.
[33] Windschitl PD, Wells GL. Measuring psychological uncertainty: verbal versus numerical methods. J Exp Psychol Appl 1996;2:343–64.
[34] Yatoo AM, Hamid B, Sheikh TA, Ali S, Bhat SA, Ramola S, et al. Global perspective of municipal solid waste and landfill leachate: generation, composition, eco-toxicity, and sustainable management strategies. Environ Sci Pollut Res 2024;31(16):23363–92.
[35] Zimmer AC. Verbal vs. numerical processing of subjective probabilities. Adv Psychol 1983;16:159–82.
[36] Zimmer AC. A model for the interpretation of verbal predictions. Int J Man Mach Stud 1984;20:121–34.