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Waste-to-energy risk perception typology: health, politics and environmental impacts

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ABSTRACT

Where strategies to reduce and recycle urban solid waste are insufficient, waste incineration is proposed as second-best management. Waste-to-energy facilities often raise remarkable public controversy, which the Not-In-My-Backyard effect does not explain sufficiently. Heterogeneous concerns lead to diverse risk perception profiles that standard psychometric scales cannot uncover. We explore this diversity of profiles by analyzing risk perceptions about a recently built waste-to-energy facility in Gipuzkoa (Spain), a case underlined by a decades-long public debate about waste management alternatives. Using Q, a semi-qualitative method, we identify risk perceptions within a diverse sample of fifty participants, including residents at different distances to the facility. We identify three main types of risk perception based on the relative importance respondents gave to 26 possible perceived risks of the facility. We define risk perception types according to the concerns that respondents with similar views emphasized most: human health, politics and institutions, and local social-ecological impacts. Whereas human-health and social-ecological concerns could be partially addressed with information—including timely and accessible reporting of effluent monitoring—and improved safety, building institutional trust to mitigate the concerns in the second risk perception type requires longer-term dynamics. Understanding heterogeneous risk profiles as done in this study can support adequate communication strategies and help policymakers prioritize governance areas to improve. Our results contribute to understanding social-environmental risk perceptions associated with controversial facilities. Using an approach that is new in this domain, these results add nuanced understanding that complements the quantitative profiling prevalent in the literature on risk perceptions and about waste-to-energy plants.

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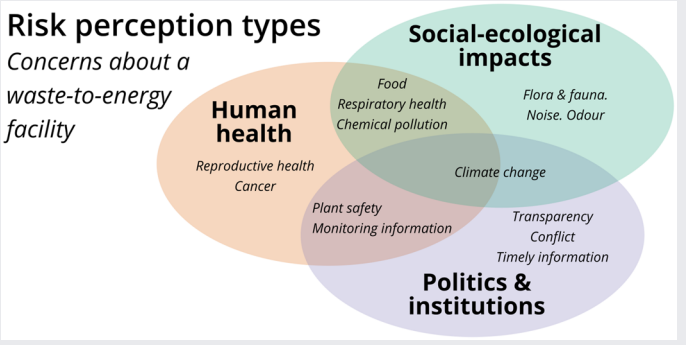
GRAPHICAL ABSTRACT



1. Introduction

In urban waste treatment, European policy establishes a hierarchy to optimize management and ensure minimal impacts on human and planetary health: preventing waste generation and re-use and recycling strategies (European Council 2008; European Union 2018), e.g. through improved packaging and industrial design. For the waste that remains, energy recovery and incineration are recommended over landfill disposal. All options have environmental impacts. Incineration can generate toxic ashes and emit polycyclic aromatic hydrocarbons and other air pollutants, whereas landfill disposal generates leachates and uncontrolled greenhouse gas (GHG) emissions, among others. The former is favored on the grounds of two main advantages, namely: reducing waste volume (Chaliki, Psomopoulos, and Themelis 2016; Di Maria et al. 2020; Ncube et al. 2021) and greenhouse gas emissions (Aracil et al. 2018; Pérez et al. 2018; Yaman, Anil, and Alagha 2020). Energy from waste-to-energy (WtE) is also associated with lower environmental impacts than fossil fuel energy (Kumar and Samadder 2017; Wang et al. 2020).

However, WtE installations have raised social concern and controversy across geographies (Baxter et al. 2016; Bena et al. 2019). People living in their vicinity are often concerned about possible health impacts (Lima 2006), including higher cancer incidence, respiratory illnesses and adverse birth outcomes. Such impacts had been associated with facilities using old technologies, although no evidence has been found for plants following current European emissions regulations (Ghosh et al. 2019; Negri et al. 2020; Parkes et al. 2020). Concerns about health risks can increase opposition and preferences for a residence change (Lin et al. 2018). In some cases, WtE plants have received social support (Achillas et al. 2011), such as where residents valued the benefits of WtE over landfilling (Huang et al. 2015; Ren et al. 2016).

It is common to associate risk perceptions about WtE with knowledge deficit or a NIMBY effect, often condemned as a self-interested or free-riding reaction. But this simplification of public positions in the environmental realm has been contested with evidence about the diversity of motivations and values underpinning opposition (Johnson and Scicchitano 2012; McLaughlin and Cutts 2018). Factors that intensify risk perceptions are diverse and reactions to perceived risk are more complex than a reductionist argument about distance to the development (see Nelson et al. 2021). Considerations that generate opposition to, or acceptance of a new infrastructure range from personal health to impacts on ecosystems. Other drivers of opposition found in the literature are perceived unfairness and development costs (Botetzagias et al. 2015), and institutional matters such as trust in authorities or procedural and environmental justice concerns (Achillas et al. 2011; Huang et al. 2015; Lima 2006; Liu et al. 2018; Ren et al. 2016; Zhang, Liu, and Zhai 2021). These are not necessarily related to citizens' distance to the development.

The urgent need to tackle growing waste generation and bring landfill disposal to an end (Lausselet et al. 2017), requires a better understanding of the risk perceptions that shape social acceptability of alternative options. The process to select the location of future WtE plants is extremely complex, and acceptance and favorable public attitudes are important to ensure the viability and sustainability of such projects (Gao et al. 2021; Gonzalez Silva et al. 2022).

Risk perceptions about WtE plants (and other exposures) tend to be measured with single items or Likert scales, then aggregated as averages into psychometric scales (with notable exceptions such as Signorino (2012), in the context of the petrochemical industry). These are then related to other variables of interest (Bena et al. 2019; Lima 2006; Lin et al. 2018). Such approach uncovers the magnitude of perceived risk across populations, its relationship with other variables or outcomes of interest (e.g. sociodemographic, or opposition and mobilization), or its development over time. That understanding helps researchers define risk perception profiles quantitatively, such as distinguishing groups by their tendency to worry. The resulting sociodemographic profiles can be used to design targeted communication interventions (Parvanta and Bass 2020).

However, these psychometric scales usually yield perceptions that are qualitatively invariant among people and have the same thematic structure. For instance, Millman, Rigby, and Jones (2021, see also Bronfman et al. 2007) have argued that individual data aggregated in psychometric scales, usually through average scores, mask potential qualitative individual differences in risk perceptions. The main difference among profiles that emerge from such analysis is quantitative, for example, that some people are more concerned than others overall. It is unclear whether qualitative invariance is an explicit assumption among scholars or a methodological shortcoming. But it is pervasive in this research area. It is also known that scales can provide little response variability, because respondents tend to score all items around a central value. As a result, studies using these approaches scarcely uncover the emphasis that individuals give to different themes relative to each other, and might be missing relevant differences (ten Klooster et al. 2008).

Instead, it might be that some respondents are deeply worried about certain potential impacts and indifferent about others—an information that does not emerge from an aggregated scale approach. For instance, teachers in schools next to a WtE facility might worry about its impact on students' health, local farmers about the contamination of their crops, restaurant keepers about the reduction of visitors, and naturalists about the effects on endemic fauna. From this point on, we refer to groups with distinct perspectives as risk perception types, or simply *types*. The existence of these types entails that risk communication strategies and social engagement initiatives should be tailored or framed to fit the different perspectives on the matter.

To uncover these qualitatively different risk perception types, we analyze heterogeneous perspectives about the reasons for concern about a newly developed and controversial WtE installation. We focus on a WtE facility in Gipuzkoa, a province in the Basque Country (Spain), which has been built near a densely populated area and is functioning since February 2020. The facility is embedded in a decades-long and politically convoluted issue of waste management, involving a landfill that remained open beyond its planned capacity (Gómez Martín 1997) and remarkable social mobilization. The flow of information comprehends multiple actors, internet and social media, and a complex interaction with identity and political ideology. Two previous studies conducted in this province revealed that the facility was one of the exposures that triggered the greatest concern among citizens, and that perceived risk for human health and trust in institutions were strong predictors of acceptance (Subiza-Pérez et al. 2020a, 2020b). A deeper understanding of the reasons for concern can inform management alternatives or more targeted strategies to address waste management and mediate and mitigate such controversies.

In the Basque Country, per capita volumes of municipal waste (MW) are similar to European averages (481 kg/person in 2018). It is estimated that around a fourth of this volume is managed

through WtE (HPKP 2021). Current waste management planning (GHHKPO 2019) prioritizes reduction, recycling and composting in that order, in alignment with European policy. Accordingly, WtE rates might decrease in the following years due to improvements in waste prevention, reuse and recycle strategies and an emerging emphasis on the circular economy. However, it is claimed that WtE will still be necessary to meet Spanish regulations limiting landfill disposal (BOE 2020; Eusko Jaurlaritza 2021).

To identify a typology of risk perception profiles related to the WtE facility, we use Q method (Watts and Stenner 2012; hereafter Q). This semi-quantitative and exploratory approach to understand perspectives helps researchers overcome some caveats of earlier analyses by providing a rich qualitative understanding of the diversity of perceptions. It is particularly suited for controversial topics, among others (Zabala, Sandbrook, and Mukherjee 2018). Q allows researchers to distinguish types of opinions or viewpoints on a given topic and their nuance (Brown 1986; Coogan and Herrington 2011), including the specific themes of disagreement and consensus among respondents. It does so by grouping responses with shared views (see Methods). The approach is used across disciplines, including in studies about waste management (e.g. McNicholas and Cotton 2019; Wolsink 2004) and public policy acceptability (Díaz and van Vliet 2018; Venables et al. 2009). Q has been successfully applied to several environmental issues such as air pollution (Sala, Oltra, and Gonçalves 2015), fracking (McLaughlin and Cutts 2018) or food contamination (Siegrist, Hübner, and Hartmann 2018).

In this study we used this approach to understand whether risk perception profiles (if any) showed distinct concerns regarding diverse WtE risks. Other techniques such as clustering can be used to group participants' views, but Q allows a deeper examination of the commonalities and differences between groups in a simpler and more explicit way (Ten Klooster et al. 2008). Therefore it is more suitable to study subjectivity.

2. Materials and methods

Using Q, researchers group responses according to the prominence respondents give to certain items (usually statements) that reflect ideas, opinions or attitudes, for example. These items are pre-selected by the researchers from the range of opinions that could possibly be said about the topic of concern.

Two main features differentiate Q from other approaches to understand perceptions. First, it uses a particular questioning format, whereby respondents are offered a set of items (Q-set) that they rank in order, e.g. from most to least agreement. They rank these items typically according to their own view, but other conditions of instruction are possible. They do so over a pre-formatted grid usually shaped as a normal distribution. The ranking implicitly gives a numerical score to each item, enabling subsequent quantitative analysis. Second, the respondent sampling strategy emphasizes diversity rather than representativity; the aim is to include respondents with different views, regardless of whether these views are held by only a minority. As a result, the sample does not need to be large, and Q studies typically include 35–45 participants (Zabala, Sandbrook, and Mukherjee 2018).

Because respondents rank the items according to their own perspective (or to their view about others' perspective, depending on the condition of instruction), each response (Q-sort) represents an individual, comprehensive expression of subjectivity—about risk perception in this case. The dataset with all individual responses is then analyzed using multivariate data reduction techniques. Analytically, responses are grouped into a few types or profiles, according to the similarity in how they ranked the items. These types are then interpreted, drawing on complementary qualitative explanations elicited after each respondent sorted the items (a reason why the method is labelled semi-qualitative).

The approach provides two main outcomes: 1) consensus items that show the topics responses agree on, e.g. statements which are similarly (un)relevant to all; and 2) distinguishing items that

show the particularities of each type (e.g. 'type 1 is extremely worried about a specific point' or 'much less worried than the other types'). Next, we follow guidelines for complete reporting of Q studies and of the analytical decisions (Zabala, Sandbrook, and Mukherjee 2018; Zabala and Pascual 2016).

For the Q-set in this study, we selected 26 statements (Table 1), each representing a type of risk that may be perceived about the facility (see Supplementary Table 1 for the original statements in Basque and Spanish) . The Q-set contains statements about the multifaceted risks (human health, environmental and social impacts) that the WtE facility might pose to the community and incorporates notions of procedural justice and trust among involved stakeholders. The concepts in each item are not mutually exclusive and many are related directly or indirectly (e.g. food contamination may trigger health issues). These are articulated as separate items to explore the distinct salience of each concept.

As usual in Q studies, these statements were selected based on several sources: prior research experience of the research team with the case study, scientific literature covering the implications of waste incineration exposure for human health and the social perceptions and attitudes towards these plants, waste incineration content in local and regional media (e.g. newspapers and TV), and social media content regarding this specific facility (from Facebook and Twitter). Typical concourse development consists of gathering as many different statements as possible, and then selecting a few. In this case, we started with few selected statements (15) and then expanded to disaggregate some generic impacts into more specific ones (e.g. environmental impacts into impacts on flora and fauna, and on climate change). We extended this to include institutional matters, identified in the literature as drivers of controversy in environmental developments. During the process of sampling the Q-set we also eliminated and merged redundant sentences iteratively, as standard. The final statements are aligned into four themes: environmental, human health, socio-economic interactions, and institutional relational values (Achillas et al. 2011; Huang et al. 2015; Lima 2006; Liu et al. 2018; Ren et al. 2016).

To ensure perspective diversity, we included respondents from a range of categories: health professionals, researchers in various disciplines, university students, local environmental NGOs, citizen associations specifically focused on the facility, local associations (e.g. cultural groups, neighbors' associations), parents' associations at the local schools, etc. These categories include a variety of backgrounds and relations with the facility. We collected contact addresses *via* publicly available information (e.g. associations' email addresses). We sent email invitations in two waves between December 2020 and April 2021, the second wave striving to collect more responses from the groups for which we had received none or few. Construction of the plant began in 2017 and operations started in a preliminary phase in February 2020, so Q-sorts were conducted between 10–14 months after WtE operations started. While we aimed to cover the variety of opinions as much as possible, we acknowledge that our P-sample may not be fully comprehensive. Therefore, the results are indicative of the diversity of concerns, but do not necessarily capture all of them.

We administered the Q-sorts online (due to public health restrictions in force at the time), using HTMLQ (Aproxima 2015) and in the two official languages of the region (Basque and Spanish), which respondents could choose. Before sending the invitations, we piloted the study with five respondents. Two of these were conducted *via* videoconferencing, which provided an experience closer to face-to-face administration and allowed researchers to gather feedback. For all respondents, in addition to the Q-sort, we collected standard background information (such as gender and age), responses about environmental attitudes, and postal code to distinguish responses from people more directly experiencing the facility. The Q-sort was presented to participants as follows. First, participants were asked to group statements in three piles, according to how the statement worried them: 'I am slightly worried', 'I am quite worried' and 'I am very worried'. The second, main part of the task was to rank the statements in a column-based grid according to how worrying the statement was.

Table 1. Set of statements (Q-set), category and abbreviated name.

Category	Shorthand name	Item
Environmental health	*01. smell*	01. The generation of bad odors
	02. noise	02. Noise generation
	03. chem.pol	03. Chemical pollution of air and water
	04. food	04. Contamination of food products produced in the vicinity
	05. cli.ch	05. Greenhouse gas emissions that contribute to climate change
	06. flo.faun	06. Degradation of nearby flora and fauna
	07. aesth	07. Negative impact on landscape aesthetics
Human health	*08. cancer*	08. Increased incidence of different types of cancer
	09. resp.dis	09. Risk of respiratory diseases
	10. abort	10. Increase of congenital malformations, abortions, premature births and impact on the health of newborns
	11. accident	11. Risk of accidents, fires or explosions that could occur in the facility
	12. traffic	12. Accidents on the road due to increased traffic caused by transport trucks
	13. stress	13. Impact on physical and mental health due to the stress, rejection or concern by citizens about the facility
Socio-economic interactions	*14. econ*	14. Economic losses: devaluation of real estate, job losses, abandonment of companies from the vicinity of the facility
	15. reput	15. The bad reputation that it may generate for the municipalities near the facility
	16. coex	16. Negative impact on social coexistence that citizens' positions and opinions about the facility may have
	17. space	17. Reduction of the use of spaces and social relationships in places close to the facility
Institutional relational values	*18. tension*	18. Tension between the interests of public institutions and those of citizens
	19. conflict	19. Conflict between the firm responsible for the facility and the public
	20. transpar	20. Lack of transparency from the institutions involved in the approval, construction and commissioning process of the facility
	21. opinion	21. Lack of integration of social opinion in decisions about the facility
	22. conf.ins	22. Lack of trust in the institutions involved
	23. conf.firm	23. Lack of confidence in the ability of the firm responsible for the safe operation of the facility
	24. safety	24. Insufficient safety measures
	25. info.det	25. Lack of detailed information on the quality of emissions and effluents of the facility, available to the public
	26. info.inm	26. Lack of immediate information on facility emissions and effluents available to the public

The final sample of respondents included 50 participants and was balanced in terms of gender (25 male and 25 female) and age (between four and eight respondents born each decade between 1950 and 2000). Among the categories (see Results), the dominant ones were those self-labelled as citizens (i.e. not belonging to other groups; 16) and university members (excluding students; 12). Other categories were students (6), members of cultural and environmental associations (7) and health workers (4). Regarding proximity to the facility, 12 respondents lived in the municipality where the facility was located, 9 lived in bordering municipalities, 24 in the province capital (close, but not contiguous to the facility's municipality) and 5 further away.

We analyzed the data using 'qmethod' for R (R Core Team 2023; Zabala 2014) to reduce the individual Q-sorts to a few types. Each type is represented by weighted average scores for each statement. To do so, we used Principal Components Analysis (PCA), Spearman correlation coefficients (in the understanding that the data are not parametric) and varimax rotation to obtain clearly distinctive components (types or perspectives). We experimented with other forms of rotation (see Akhtar-Danesh 2017), but a preliminary interpretation of the outcomes of each rotation suggested that a varimax solution was parsimonious and informative.

We also conducted several tests of quality and internal consistency of the data. We inspected the correlation matrix of all respondents to identify potential outliers (those with exceptionally low correlations with all other responses). We conducted a preliminary interpretation of results obtained

by extracting two and four components instead of three. We found that the third factor provided an informative additional view compared to extracting two, whereas the fourth factor was conceptually similar to the first. Including a fourth factor blurred the interpretive differences between the other three, which were clearer when choosing three components only. We inspected the automatic pre-flagging of factor loadings of the final solution and found them to be satisfactory (e.g. that no *flagged* response loaded high in more than one factor), so we continued with automatic pre-flagging.

Q-sorts flagged for each factor are those responses that are most representative (those with higher absolute factor loadings), and subsequent estimations use only these responses. Then we calculate, as standard, the weighted average response for each factor or type—the ranking of items that best represents those responses grouped into each type.

3. Results and interpretation

We grouped analytically all responses into three factors or types (abbreviated as F1, F2 and F3 hereafter), which explain 61% of response variability. Each factor is represented by 27, 10 and 7 responses respectively (flagged responses, indicated with a star in Table 2). Six responses did not have a significant factor loading on any factor or had moderate to high factor loadings in two or more factors. These are considered confounding responses. The factors have low correlation among themselves (0.08, 0.33 and −0.21 for the pairs F1-F2, F1-F3 and F2-F3 respectively), meaning that the perceptions represented by each profile are clearly distinct. Descriptive statistics of the observable characteristics of respondents associated with each perspective show no clear pattern.

The perception of each of the three types is defined by a ranking of statements and the score associated with each statement (z-score), also relative to other factors (Figure 1). The z-score is the weighted average score given to a statement by respondents flagged in each factor, as indicated above. Eleven statements distinguish all perspectives from each other (indicated with a star in Figure 1, e.g. S08 about cancer incidence), and two statements are clearly of consensus (at the bottom of Figure 1, e.g. S14 economic impacts).

As an additional analytical step, we identified the most salient themes, which we define as those selected with highest frequency of most or least concern (if respondents placed them in the extremes of the ranking). The statements most often selected as of major concern were about cancer, chemical contamination, respiratory disease, and abortion (S08, S03, S09 and S10). The ones most selected as of least concern were about traffic, coexistence, reputation, aesthetics, and public spaces (S12, S16, S15, S07 and S17). About community coexistence[1] for example (S16), many respondents chose this as of least concern, arguing that they perceive a consensus in the municipality against the facility, which entails minimal risk of social confrontation.

3.1. Themes of consensus: climate change and facility safety concerns

According to participants' answer to the complementary questionnaire, acceptance of the facility was low overall, although the degree of concern varied. Some qualitative answers expressed worry about almost all statements and stated that they would have placed more in the category of most concern. Other answers stated the opposite and were not too concerned with health issues, for example, expressing confidence in modern technology already deployed in other European locations.

Focusing on the factor results, two themes emerged as of most agreement among all types (Figure 1 bottom two statements, S14 and S12): traffic accidents and economic losses for the area, which both coincided to be of low concern. Relatively high concerns about climate change (S05) and facility safety (S24) were common across the sample too. This aligned concern over climate change might be due to the generalized increase of public awareness in recent years. Several respondents believed the facility would add noticeably to the carbon emissions of the province, while one pointed at the lock-in effect of such an

Table 2. Asterisks indicate respondents flagged for each factor. Respondents are ordered by factor scores. Gender = 0 for female. Location codes: 1, same municipality as the facility; 2, immediate municipality; 3, nearby municipalities (including provincial capital); 4. further away within the region. Category of 'Citizen' refers to respondents not identified with any of the other categories. The first two letters of the ID indicate the language used in the response.

ID	F1	F2	F3	Gender	Age group	Location	Category
ES12041229	0.90*	0.03	−0.01	0	(20,40)	3	Student
EU03161008	0.90*	0.07	0.10	1	(40,60)	1	Citizen
ES03180854	0.89*	0.14	0.10	0	(40,60)	1	Cultural assoc.
EU04150535	0.89*	0.08	0.24	1	(20,40)	2	Cultural assoc.
EU03170149	0.88*	0.05	0.14	1	(40,60)	2	Citizen
EU03020859	0.84*	0.19	0.23	0	(40,60)	3	University staff
ES03160432	0.83*	−0.05	0.07	1	(40,60)	1	University staff
EU03160822	0.81*	0.17	0.20	1	(40,60)	1	Neighbors assoc.
EU03170928	0.80*	−0.23	0.21	0	(40,60)	2	Citizen
EU03171110	0.80*	0.18	0.17	1	(60,80)	1	Citizen
EU03160942	0.78*	0.02	0.14	1	(40,60)	2	Citizen
ES03170936	0.77*	−0.20	0.16	1	(40,60)	1	Citizen
EU04200452	0.76*	0.11	0.27	0	(20,40)	2	Cultural assoc.
ES02040928	0.73*	−0.01	0.22	0	(40,60)	4	University staff
ES02030530	0.72*	−0.22	−0.13	0	(20,40)	4	Student
ES03161008	0.72*	0.06	0.19	0	(40,60)	3	Citizen
EU04150305	0.71*	−0.24	0.23	1	(20,40)	2	Cultural assoc.
EU12040956	0.71*	0.28	0.00	0	(20,40)	3	NA
ES03160647	0.68*	−0.15	0.43	0	(40,60)	1	University staff
ES04081126	0.68*	0.03	0.32	0	(20,40)	3	University staff
ES01260824	0.67*	0.33	0.39	1	(40,60)	2	Health worker
ES04080301	0.67*	0.04	0.40	0	(20,40)	3	Citizen
ES12090453	0.67*	0.45	0.06	0	(60,80)	NA	NA
ES03160302	0.65*	−0.07	0.42	0	(40,60)	2	Student
ES03170736	0.61*	0.07	0.38	1	(40,60)	1	Citizen
EU12050543	0.46*	0.33	0.30	1	(40,60)	NA	University staff
EU01270328	−0.74*	0.39	0.11	0	(40,60)	3	Citizen
ES12211217	−0.15	0.87*	0.09	0	(60,80)	3	Citizen
ES04120645	0.22	0.75*	−0.30	0	(60,80)	3	Health worker
ES04080110	0.32	0.74*	−0.07	1	(20,40)	3	University staff
ES04180914	0.35	0.72*	−0.08	1	(40,60)	4	Cultural assoc.
ES04120327	−0.05	0.61*	−0.26	1	(40,60)	3	Citizen
ES04080402	0.28	0.53*	0.30	0	(60,80)	3	Citizen
ES04281012	0.11	0.53*	−0.02	1	(40,60)	3	Commercial assoc.
EU04081140	0.22	0.51*	−0.36	1	(20,40)	3	Citizen
ES01270906	0.35	−0.64*	0.06	0	(40,60)	3	Health worker
ES03160902	0.48	−0.55*	−0.03	1	(40,60)	1	University staff
ES02010548	−0.02	0.17	0.80*	1	(20,40)	3	University staff
ES02030537	−0.14	−0.48	0.68*	1	(20,40)	3	Student
ES03160945	0.18	−0.16	0.44*	0	(40,60)	1	Student
ES04210433	0.13	−0.3	0.43*	1	(20,40)	3	University staff
ES12170737	0.37	−0.36	0.69*	1	(20,40)	4	Student
EU04080851	0.18	0.44	0.54*	0	(20,40)	1	Citizen
EU12030713	0.26	−0.13	0.49*	1	(20,40)	2	Environmental assoc.
ES01300736	−0.53	0.51	−0.24	0	(40,60)	4	University staff
ES02010613	0.2	0.00	0.30	1	(60,80)	3	University staff
ES04051042	0.45	−0.51	0.60	0	(40,60)	1	Cultural assoc.
ES04120908	0.59	−0.21	0.58	0	(40,60)	3	Citizen
ES04191209	−0.53	0.54	−0.22	1	(60,80)	3	Health worker
EU04130353	0.46	−0.52	0.38	0	(20,40)	3	Citizen

investment, which could become a stranded asset. Notably, concerns over safety of food grown in the area (S04) were shared between two types (F1 and F3). While this is not a consensus theme because F2 did not engage much with it, it is noteworthy given the remarkably high scores assigned by F1 and F3, which place it among the four items of highest concern. Further, across qualitative responses, many participants spontaneously expressed that health and the environment should be prioritized above economic considerations (whereas no one expressed the opposite view).

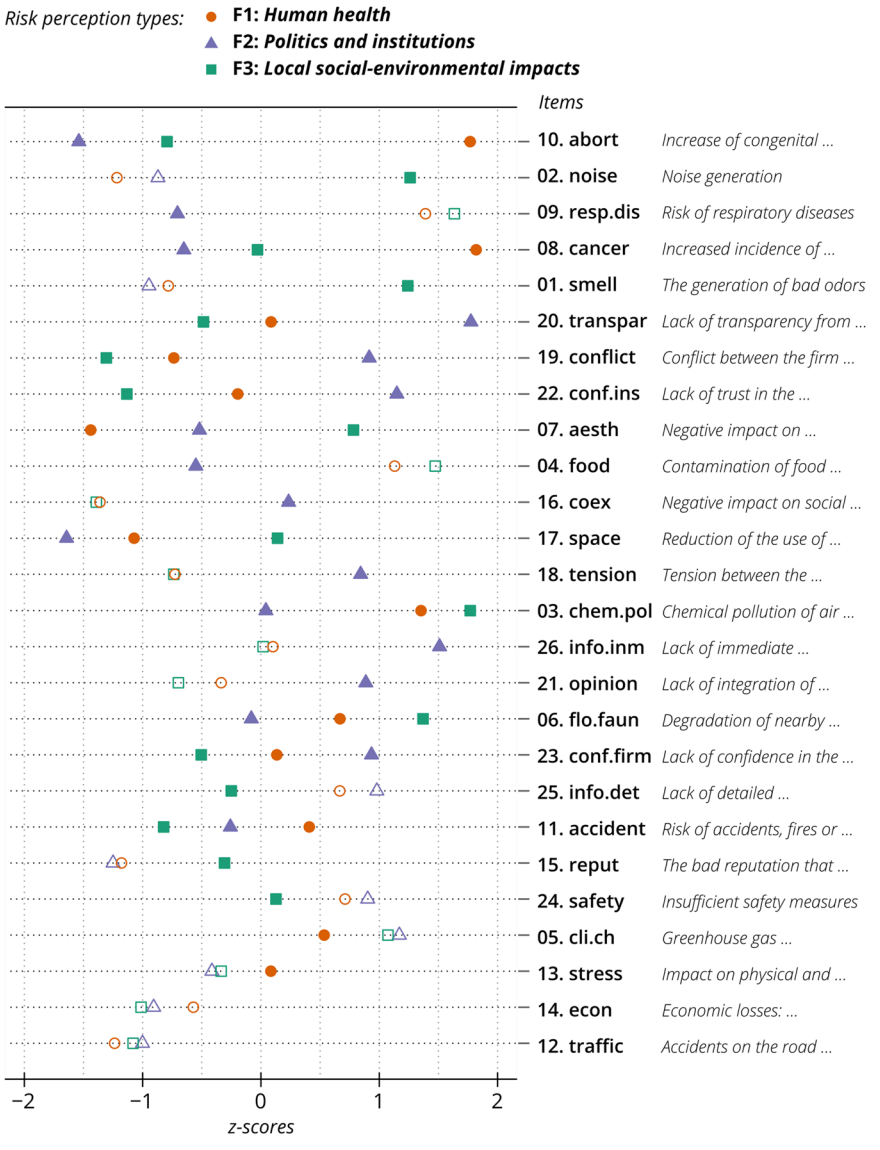


Figure 1. Plot of z-scores that associate each statement with each perception type. Statements (perceived risks) are ordered from most disagreement among the types (top) to most agreement (bottom). Distances between icons indicate the level of discrepancy between types in their perceived relevance of each risk. Filled icons indicate distinguishing statements. Distinguishing statements can differentiate among the three groups (e.g. S10) or between one and the rest (e.g. S02).

The following sections interpret each of the three perspectives, which we name based on what distinguishes them most from the others.

3.2. F1: human health

This type is mostly concerned with health matters, predominantly reproductive health (S10) and cancer (S8). It is moderately but distinctly more worried than the others about mental health (S13) and accidents at the facility (S11). These concerns are articulated also in terms of future generations being a priority over current economic interests. Some respondents cite international impact studies. Perceptions appear exacerbated by reported sighting of smoke from the facility

(See quotes in Table 3, and Supplementary Table 2 for the original quotes in Basque and Spanish), which aligns with this type's distinctive concern about the stress caused by the facility (S13*[2]). Some respondents expressed their frustration because their earlier efforts to improve recycling felt unrewarded, given the facility was built nearby and that the view of the facility elicits a negative affect daily (Quote in Table 3).

This type is noticeably the least concerned with landscape aesthetics (S7) and moderately but distinctly less concerned about climate change impacts (S05*). As a contrast, the three respondents least concerned with reproductive health (S10; respondents not in this type, who had an approximately opposed view) backed their choice citing belief, hope and scientific evidence, respectively (qualitative data).

3.3. F2: politics and institutions

This perspective is clearly defined by their concern about trust in the main agents involved and the politics around the issue, including lack of institutional transparency, trust in institutions and possible conflicts between citizens and the firm managing the facility (S20, S19, S22). For example, respondents worry that the firm puts business interests above those of citizens—an argument presented together with concerns over trust in the firm's capacity regarding safety. They envision future conflicts, by mentioning conflict resolution mechanisms, the judiciary and the loss of trust that conflicts could trigger. This type is clearly more concerned than the rest about social coexistence, tensions of institutions with citizens, and lack of social participation in decisions (S16*, S18*, S26*). For example, some highlight concerns about corruption, and that the facility appears to be a political tool, even if the facility could be well managed from a technical and safety point of view (Table 3). Their concerns about transparency and lack of trust are reinforced by worries about information on pollution monitoring not being publicly available immediately (S21*). According to respondents (qualitative data), monitoring should look at cumulative gases and effluents as well as peak emissions, to ensure these are within the safe range. Some also question whether such information, if available, would be provided in an accessible, understandable form.

In contrast, issues about human health, food contamination and public spaces are of least concern for this type (S10, S09*, S08, S04*, S17). While relatively important, matters about damage to biodiversity and water and air pollution (S03, S06) are also of less concern than for other types. Interestingly, among those who, instead, did not emphasize trust in institutions as a concern, some argued this was because there is already little confidence and so it could not be reduced much further.

3.4. F3: local social-ecological impacts

This type is clearly differentiated by stronger concerns about the most visible impacts near the facility: noise, odors and visual impact (S02*, S01*, S07). It is more concerned than the rest about the use of social and public spaces and the reputation of nearby municipalities (S17 and S15*). It is also noticeably worried by chemical pollution of air and water, and the impacts on flora and fauna (S03, S06). The least concern is about conflicts between the firm and citizens as well as trust in institutions (S19, S22), and moderately (but lower than the rest) transparency, trust in the firm's capacity and risk of accidents in the facility (S20, S23, S25*, S11, S24*).

Several qualitative answers reported noise and odor impacts already happening (soon after the facility started functioning), and some described a continuous background noise in the vicinity, which can affect sleep severely (qualitative data). Interestingly, other respondents (not in this type), dismissed the importance of noise and odor, by assuming that these would be dealt with technologically and that an appropriate location had been chosen.

Table 3. Example quotes from respondents by risk perception type.

F1. Health concerns	F2. Politics and institutions	F3. Local social-ecological impacts
(s10) 'I am concerned about my family's health and what the government has hidden about this facility. I live [nearby] and as soon as the weather is bad the smoke is incredible.' 'The health impact of the incinerator seems to me the most important' 'I am concerned about the health of our children and future generations, and as has been shown in other countries, incinerator emissions directly affect it.'	(s20) 'All the initial management and how it started functioning is a 'black hole'. A clear example is the ammonia spill that occurred at the time and affected the environment and its waters.' 'The amount of news about non-transparent processes and cases of corruption regarding how this style of work is awarded to companies generates concern in this case.' (s19)	(s1) '[smell] is very unpleasant and unbearable' (s2) 'I live [nearby] and at night it's especially horrible to hear the noise, like a giant turbine, which can also be heard inside our home depending on the wind.'
(s8) '(…) the deterioration of citizens' life quality is not a risk that can be assumed in exchange for economic benefits.' 'Various studies in Europe have shown a significant increase in cancers in the vicinity of these plants.'	'The employer does not want to lose money, he is willing to do whatever to avoid that, even if it is not entirely within the law. Therefore, some for partisan games, others for fear of harm… I'd be distrustful.' (s22)	'There is a background noise that makes me very nervous and is generating anxiety. Suddenly it stops, and that's when I get to sleep again. I have to say that not everyone hears it, or not everyone is upset, but it's making me extremely nervous.' (s6)
(s13) 'I see [the facility] every day, polluting us and unable to do anything. It makes me feel very angry and powerless. We were the first town to recycle with the [door to door] system and they give us such a 'gift'. It's ironic, isn't?'	'Cases of corruption in public administration are the order of the day, which makes me question the honesty of those who are part of the decision-making process.' 'Politics is intrinsically linked to my assessment. The facility is a political weapon. I think it can be handled well from a technical point of view and there are examples of similar facilities in European cities, always with very strict safety measures and sufficient financial resources to carry out proper maintenance.'	'Human action has already affected the environment a lot and especially its flora and fauna. The surrounding flora and fauna are the thermometer of this negative human impact, and it worries me a lot that they are already sufficiently punished, let alone to cause even more damage as a result of an installation that I don't see necessary. I believe that the construction of such a facility when the environment's health is in such critical state, is a complete irresponsibility, both in terms of the climatic situation in the world in general and the quality of life of those around us.'

Qualitative explanations provided for statements that distinguish each perception. Quotes are by respondents who placed the given sentence as of most concern. Location names have been removed for anonymity.

4. Discussion

The construction of waste incineration plants is often accompanied by social concern and opposition. In the context of a WtE facility recently built in Gipuzkoa (Spain) that has been remarkably contested, we elicited perceptions from a diverse sample of actors. The sample was well balanced in terms of gender, age, occupation and distance to the facility. We identified and defined three main risk perception types according to their most salient concerns: 1) impacts on human health, 2) political and institutional aspects, and 3) local social-ecological impacts.

Our results broadly support the conclusions of earlier studies and align with most risk themes we identified a priori (see Table 1). Our findings capture—in a single sample—the themes that previous separate studies have identified in isolation: that major drivers of such responses are the expected negative consequences for people's health, the environment, and social considerations such as trust in institutions, transparency and justice (Achillas et al. 2011; Huang et al. 2015; Liu et al. 2019, 2018; Zhang, Liu, and Zhai 2021).

4.1. Two perspectives on health and a third distinct view

The first type represents the largest part of our sample. This perspective showed great concern about the potential increase in the incidence of cancer and reproductive health problems that might come paired with the activity of the facility. This type was also more preoccupied than the rest by impacts on mental health and the occurrence of accidents. The concerns of F2 were dominated by socio-political dimensions around the construction and management of the facility. Specifically, it pointed at the lack of institutional trust and transparency, and the tensions between citizens and other stakeholders. This type gave less prominence to health and environmental issues. F3 was more concerned with deleterious consequences that the facility might bring to flora, fauna and local chemical pollution. This type also emphasized the noise and odors in the vicinity of the facility—already experienced—and show lowest concern over socio-political matters.

Human health implications were the dominant concern for F1 and, to a lesser extent, also for F3. This suggests a strong connection between the first and third types, because they are both associated with potential impacts on health, albeit with different focus (human or planetary health). Both types are remarkably worried about air and water pollution, although possibly for different reasons. This alignment between F1 and F3 highlights the uniqueness of the F2 type, chiefly concerned with politics and interactions with institutions.

4.2. Addressing perceived risks

Understanding the distinct risk perception types or profiles can be useful to identify interventions to mitigate the negative affect and stress derived from a facility. The first and third types can be addressed, to a large extent, with information strategies, such as avoiding misinformation, providing transparent and immediate pollution monitoring data, and systematically collecting and communicating evidence of impacts. An informational strategy assumes as precondition that safety is guaranteed. The second type, however, involves enhancing confidence in institutions. This goal requires long-term strategies beyond providing information, focusing, for example, on increasing the amount and frequency of trusted interactions (see below). Building trust can arguably be more complex and uncertain than diffusing information, but its benefits could spill over positively to other institutional dynamics too.

An overall objective of risk communication can be to adjust perceived risk to the objective risk that a given exposure might mean for the community (Lipkus 2007; San Juan and Vozmediano 2021). In public health, risk communication and so-called participation are often quantitative, unidirectional endeavors: raising awareness among as many people as possible about risky exposures with large potential impacts, and/or decreasing worries about innocuous or scarcely dangerous ones if they are a matter of social concern. Nevertheless, if concerns across members of the community vary in quality and emphasis, as found in this study, communication strategies should be tailored to those patterns. Health and risk communicators have frequently resorted to demographic profiling and targeting (Parvanta and Bass 2020). This has been shown to be more effective than non-specific messages addressed to broader audiences. But a risk perception typology like the one presented here can further improve targeting for effectiveness.

Our results suggest that, if more communication activities were conducted in relation to this specific WtE facility, attention should be paid to the different patterns of concern among the population. These concerns structure along three clearly different themes: prevention or mitigation of potential negative human health outcomes, (mis)trust in institutions, and reduction of social-environmental impacts. We argue that communication strategies with messages that do not target the genuine matters of concern of a given person or group may be less effective at mitigating risk perceptions. Oppositely, if the message relates to the receptor's values, interests and worries, its content may be more meaningful to them; they may devote more time and energy to process it and update their beliefs and thoughts (Tortosa-Edo et al. 2014). Similarly,

messages addressing issues that are consensual but have limited relevance in this case, such as traffic accidents or economic loss due to the WtE plant activity (albeit these are concerns in other contexts), might have null impacts on attitudes, and this is important to know for practice.

Although intellectually appealing, these arguments require further validation through future studies, such as with experimental settings. In the same vein, these findings may be relevant in other locations where WtE plants are planned or under development.

Most work in the field of social acceptance and positive public perceptions about environmental infrastructure consider environmental aspects (e.g. emissions), impacts on human health (e.g. cancer) or logistic aspects (e.g. waste transport). Even though many refer to public perceptions, attitudes and support, the treatment of these psycho-social variables is superficial most of the times (Gao et al. 2021; Gaska et al. 2021; Gonzalez Silva et al. 2022). Our study, while not developed to inform WtE plant location decisions, can be helpful to highlight the complexities of public attitudes and risk perceptions and inspire better participatory processes at planning stage and when exploring locations for new such infrastructure.

4.3. Building trust

Literature on controversial infrastructures has consistently stressed the importance of institutional trust (Guo, He, and Lian 2017; He et al. 2018; Subiza-Pérez et al. 2020b). The second risk perception type in our study was defined by the perceived lack of transparency and trust in institutions, which may trigger tension and conflict. Human and ecosystem health concerns (defining F1 and F3) could be addressed through information and improved safety, but institutional trust is much harder to strengthen. Because institutional trust also affects dynamics in other policy matters, a strategy to enhance it could yield more widespread benefits, including positive spillovers into other realms and despite being costly and long. Risk communication is not just a formal top-down dissemination of risk-related information but rather a relational activity between institutions, stakeholders and affected populations (Hung, Li, and Hung 2020; Lundgren and McMakin 2018). In this relationship, trust, confidence and transparency are key, supported by increasing social participation (Sellnow 2015).

To enhance trust, researchers distinguish between social trust and competence-based trust (also called calculative; Earle 2010; Siegrist 2021). Social trust emerges when a person or group perceives that a given institution or agent shares their main values and intentions. Competence-based trust is a result of positive or effective institutional behavior in previous situations. Previous research has shown that social trust dominates over competence-based trust and might even be a predictor of the latter (Earle and Siegrist 2008, 2006). Competence-based trust is also more fragile to actions or situations violating confidence generated prior in time. However, this case is in a highly politicized context,the plant is a very salient environmental risk for the public, and strengthening social trust might be a very difficult task. Supporters and detractors of the WtE plant might strongly differ on their views about economics, environmental issues, and social organization, which could easily undermine any initiative to achieve consensus. In contrast, competence-based trust can be more easily achievable if reflexive participatory strategies are undertaken, such as involving and listening to multiple social actors, and institutions acting honestly and transparently and taking effective action as a result. This includes solutions implied from some of the statements, such as prompt, public and reliable information about environmental monitoring, and taking action to ensure that spills do not occur, and that odour and noise nuisances are minimal.

In the case of the WtE facility studied here, trust-reinforcing strategies could address concerns about the socio-political dynamics surrounding the facility. Moreover, they could synergize with strategies to target the other risk perception types, by demonstrating that institutions act upon people's health needs and concerns. However, news about non-authorized effluents emanating

from the plant after our data collection have not contributed to such trust-building efforts and somewhat strengthen risk perception rationales.

4.4. Limitations and future research

The extent to which these results explain broader phenomena is limited by common methodological considerations regarding the sample of statements and of respondents in Q studies, which suggest avenues for future expansion of this area of enquiry. We designed the Q-set after a comprehensive review of scientific literature on health and environmental impacts of WtE plants and on risk perceptions, and of online social and conventional media content. Quickly emerging and transforming social representations of WtE plants' risks might not have been captured in this sample of statements. These could be identified with further in-depth interviews with relevant stakeholders. Due to the exploratory nature of Q and the usual respondent sampling that targets diversity, results are not proportionally generalizable to the broader community influenced by this WtE facility or to populations living near other WtE plants.

Further considerations for future research associate with the specific research topic. Whether risk perception types are individual or collectively held is difficult to disentangle, and this is important because social networks and initiatives influence individual perceptions and mitigate or reinforce certain messages. Our study design is also unable to capture an important opposing argument: some may disagree with this waste management alternative, arguing that more emphasis should be given to reduction and recycling strategies, and that incineration deviates institutional efforts from the former. This argument goes beyond risk perceptions and into the realm of decision making over solutions. It is somewhat associated with the 'policy and institutions' perspective, although not explicitly captured in our study. Future studies focused on solutions to the issue, rather than on risk perceptions, can shed light on the role of institutional trust and how to mitigate its deficit. In addition, forthcoming research should be sensitive to the intricate trade-offs between perceived risks and benefits of controversial facilities, as it has been developed elsewhere (Wang et al. 2021).

5. Conclusion

Our results contribute to the literature on risk perceptions about controversial facilities associated to social-environmental challenges. This analysis of risk perception types advances previous literature, dominated by quantitative profiling, by exploring whether diverse risk perceptions exist and how they differ qualitatively. To achieve this, we used a methodology that has not been applied before in the context of WtE plants. Q is an established approach to explore complex perceptions and attitudes towards social phenomena. It allows researchers to uncover qualitative and subjective nuances of risk perceptions, while overcoming limitations of socio-demographic or quantitative profiling.

The existence of a risk perception typology in relation to WtE plants, as found in this study, has important implications for risk communication and management initiatives and programs. Such knowledge can help practitioners define targeted strategies to mitigate concerns and/or build trust in a deeper and more meaningful way, by considering psychosocial aspects and attitudes as well. This nuanced understanding can inform the development of messages targeted to the specific concern of each type.

Current and future responses to challenges in the fields of sustainability, energy and waste require calling upon developments that may be socially controversial. Public opposition might derive from a plethora of considerations such as health-related concerns, environmental concern or trust in involved stakeholders. New developments need to be sensitive to the multi-faceted nature of risk perceptions, including delivering finely tailored messages, and coordinating

appropriate, effective participatory processes. To prioritize interventions, understanding the multiple attitudinal profiles present in the communities of interest can be key. To contribute to this understanding, we isolated three different risk perception types in relation to a controversial WtE facility recently built. This typology can inspire effective risk communication and management strategies, and also inform planning and governance in other locations and for other kinds of facilities at the interface between human and planetary health.

Notes

1. *Coexistence* in this case is the closest translation for the Spanish word "*convivencia*" (the word used in the Q-set), which refers broadly to peaceful relations between social groups—a culturally and historically important value in the region.
2. In the text, asterisk after the ID of a statement indicates that the statement was distinguishing for this factor only, whereas the other two factors were in agreement over it.

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Disclosure statement

The authors report there are no competing interests to declare.

Geolocation information

43.2580184, −2.0395941 (degrees in decimal point form).

Data availability statement

The data are available from the authors upon reasonable request.

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