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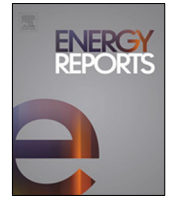
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## Research paper

## Stakeholders' perceptions of Helium and Carbon Dioxide risks in a subsurface engineering project in France

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## ABSTRACT

Projects with a high socio-environmental impact involving the subsoil are often the subject of strong controversy between stakeholders, sometimes affecting their implementation. Thus, increasing attention is being paid to understanding the public perception of the risks associated with these projects. The objective of this research was to understand how social and psychological anchors influence the way stakeholders perceive the risks associated with a helium (He) and carbon dioxide (CO<sub>2</sub>) valorization project in central France. A survey was conducted among 306 people living in two geographical areas, one affected by the project and the other not affected. Verbal association tasks were used to investigate perceptions of He and CO<sub>2</sub> and the data were then subjected to two correspondence analyses.

**Results:** The results show that He's perceptions are not yet totally structured by psychosocial anchors but are nevertheless structured by the territory variable. For CO<sub>2</sub>, the participants' discourse is organized around the notion of risk and refers to the impact of CO<sub>2</sub> emissions on the environment. Moreover, perceptions are influenced by psycho-social anchors, which clearly structure the perception of CO<sub>2</sub>. On the other hand, for this object that is well known to the general public, the territory no longer seems to play a role in structuring perceptions.

**Conclusion:** This research highlights the importance of studying the psychosocial anchors involved in the appropriation of objects related to projects, in order to develop and adapt suitable communications according to the characteristics of the stakeholders and the territory in which they are evolving.

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## 1. Introduction

In 2021, the latest report of the Intergovernmental Panel on Climate Change (Masson-Delmotte et al., 2021) once again reminded the world of the urgent need to take effective action against climate change. Public authorities must find a balance between the growing increase in energy needs and the reduction of greenhouse gas emissions. The objective is to comply with the global agreement reached at the 21st Conference of the Parties (COP21) in 2015, which aims to limit global temperature increase to less than 2° by 2100. In this increasingly strained context, some states wish to regain a form of independence with regard to certain critical inputs (e.g., minerals, rare gases) in order to

reduce the carbon impact of imports. On March 16, 2022, the French Prime Minister detailed the measures of the economic and social resilience plan: France 2030,<sup>1</sup> which presents measures to secure strategic supplies of the most critical inputs such as rare gases. For the public authorities, the project is to allow companies to develop locally, new production channels in order to satisfy the requirements of the energy transition (e.g., capture, storage, exploitation or recovery). This local development is also accompanied by a legal obligation (in France: Barnier Law of February 2, 1995) to involve in decision-making the various stakeholders likely to affect or who are affected by the projects (Freeman, 2010; Schiller et al., 2013). Public authorities are also increasingly aware that involving stakeholders is

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<sup>1</sup> Economic and social resilience plan: France 2030 mobilized to secure the supply of critical inputs, strengthen energy sovereignty and reinforce Europe's food sovereignty. <https://www.gouvernement.fr/plan-de-resilience-economique-et-sociale-france-2030-mobilise-pour-securiser-l-provisionnement-en>.

a necessary condition for project implementation (Mercier and Arnauld de Sartre, 2021). Stakeholder involvement can lead to shared and appropriate decision making (Renn, 2006), greater legitimacy of decisions (Svarstad et al., 2006) or a reduction in the intensity of conflicts (Young et al., 2010). However, these projects regularly face a lack of acceptance from local populations due to the risks associated with the technologies they involve (Bui et al., 2018). The challenge for proponents is therefore to take into account how the risk associated with potential impacts will be perceived, for example, through communication or debate that would present the costs and benefits of a project (Slovic, 2000). However, in these large projects, the lack of communication and debate leads to an increased sense of risk which results in crystallizing stakeholder opposition and then in some cases implementation failure (Feenstra et al., 2010; Markusson et al., 2012). These projects are therefore not without controversy, as they are often the subject of strong (environmental and social) contestation, as in the case of the Ultra-Low Carbon Steelmaking project (ULCOS) or Shell's proposed Carbon Dioxide capture and storage project in Barendrecht (Netherlands).

These implementation difficulties highlight the complexity for project proponents to develop risk communication. Indeed, geologic risk communications face several specific issues such as: (1) the difficulty for individuals to imagine the subsurface, as well as the impact of technologies on the subsurface, which is often associated with sometimes erroneous or incomplete perceptions and ideas (Gibson et al., 2016); (2) the complexity of the language used by geoscientists (Liverman, 2010); (3) the emphasis of communications conveying technical and scientific information on the potential and statistically tested hazards of a technology (e.g., the risks of nuclear accidents are statistically low) without much consideration of how people might interpret it (Kunreuther and Slovic, 1996). Thus, if from the expert's point of view, the danger can be statistically quantified, the perception of the risk associated with it is socially constructed (Slovic, 1999), especially because the information is perceived through the filter of the social relationship that the individual has with the object (e.g., Joffe, 2003; Wagner et al., 1999). These individual and collective filters contribute to the construction and dissemination of risks through interpersonal and media communication and allow stakeholders (e.g., local residents, politicians or project owners) to interpret, process and adapt to emerging threats (Wagner et al., 2002). This idea of a social filter is central to the concept of Social Amplification of Risk (Kasperson et al., 1988). This concept has been popular in the literature for its dynamic and comprehensive aspects in the analysis of risk perception (Lofstedt, 2015). According to this framework, the occurrence of an event or potential event related to risk (e.g., such as an earthquake during gas extraction) will be perceived in the form of an image or symbol and will be filtered according to different factors (e.g., psychological, social origin of the individuals, geographical proximity, knowledge etc.). Then, the information will pass through "amplification stations" (Kasperson et al., 1988) such as media artifacts that will attenuate or increase the risk perceived by individuals and groups (e.g., Renn et al., 1992). Nevertheless, some authors point out that this model suffers from a relative complexity due to the numerous factors to be taken into account in the analysis, which tends to complicate the empirical use of the concept (Bearth and Siegrist, 2022).

There are many psychological and social filters that can influence risk perceptions. For example, they will perceive risk according to their socio-cultural values (Slovic, 2016), their knowledge (Siegrist and Árvai, 2020), their beliefs, the context (e.g., trust in experts) of their emotions, their place in society (Raue et al., 2018). Furthermore, many authors (e.g., Brasier et al. (2013) and Whitmarsh et al. (2015)) about shale gas, underline the interest

of taking into account environmental concerns to predict perceptions and attitudes. Graham et al. (2015) after analyzing different surveys on the perception of risks related to unconventional gas development show that some dimensions are commonly studied: attitude, familiarity, knowledge and trust. Risk perception would also be impacted by direct experience with the project (Slovic et al., 1979). Indeed, risks related to a local project, experienced (e.g., drilling, noise, pollution, odors etc.) by stakeholders may appear more important than the global risks (Slovic et al., 1978). This distinction is also reflected in "Not In My Back Yard" (NIMBY) attitudes and behaviors, a term often used by project supporters to discredit local opposition to publicly approved solutions (see, Bell et al. (2005) and Burningham (2000)). On the contrary, a 2012 study by Jacquet (2012), shows that participants living near wind turbines had more positive attitudes towards them. Tan et al. (2019), also suggest that perceptions of gas should be analyzed by comparing at least two territories, one that would be directly affected by the project and one that would not. Desbarats et al. (2010) also point out that successful communication about a project requires an understanding of the existing local context. The authors suggest carrying out a preparatory analysis to identify the factors that may influence the perception of risks by stakeholders.

A vast field of literature is directly dedicated to the analysis of stakeholders in projects (Friedman and Miles, 2006). For Reed et al. stakeholder analysis aims to study the social relationship that participants have with projects (Reed et al., 2009). Specifically, the authors consider that engagement in decision-making processes involves three methodological steps to be followed in stakeholder analysis: (1) Context analysis; (2) Application of stakeholder methods and (3) Actions. Step 2 specifies the methods needed to: identify stakeholders and their issues; differentiate between and categorize stakeholders; investigate relationships between stakeholders. However, this second step includes only a few methodologies (e.g., Q methodology, Stakeholder-led stakeholder categorization) that explain the way in which one should go about analyzing people's perceptions. Moreover, the 3-step method proposed by the authors does not directly include sub-steps for analyzing the psychological relationships (e.g., Attitudes, Perceptions of Risk, Environmental attitudes etc.) that the stakeholders have with the projects. Moreover, in practice it is often an analysis that aims to categorize stakeholders in terms of legitimacy, urgency and power that is used (Mitchell et al., 1997).

Analyzing the social relationship that stakeholders have with projects and in particular their relationship to risks in projects related to the energy transition therefore requires an examination of the psychological positioning and perceptions of all stakeholders concerned by the project. In this perspective, a body of literature, initiated by Moscovici in 1961 (Moscovici, 1961), has focused on analyzing the social construction of stakeholder perceptions. This model makes it possible to understand how individuals and groups deal with an issue, a risk, or a familiar (or unfamiliar) social object in order to give it meaning. They are, in a way, naive theories of the social environment (Jodelet, 1984) that seek to make the understanding of the world more accessible. They aim to interpret reality and are composed of opinions, attitudes, beliefs and information related to an object or situation (Rateau et al., 2011). The study of perceptions is one of the best ways to understand how a communication conveying scientific knowledge is transformed in the common sense (Moscovici, 1984). Among the theoretical orientations for understanding social representations, Doise (1990) socio-dynamic approach states that perceptions are also to be linked to individuals' social affiliations. These perceptions are constructed from individuals' social anchors (e.g., David et al. (2021) and Palmonari and Emiliani

(2016)). Following this perspective, perceptions are “constructions that are embedded in relationships of convergence or divergence between social groups” (Moliner and Lo Monaco (2017), p.85).

The study of perceptions according to the social anchors and psychological filters of the stakeholders involved in a project could be a suitable way to accompany promoters in developing a project. This would make it possible to identify possible points of conflict and contestation in order to develop communication adapted to each of the stakeholders. It is precisely a study of perceptions that was conducted with stakeholders involved in a project of production and valorization of Helium (He) and Carbon Dioxide (CO<sub>2</sub>): the project “Fonts-Bouillant”.

### 1.1. 45-8 Energy and the “Fonts-Bouillant” project

45-8 Energy, is a mining company created in 2017, its main activity is the exploration of Helium and Hydrogen (N<sub>2</sub>) and their associated resources. The company is currently developing several projects, in France and internationally. Among them is the “Fonts-Bouillants” project, the first Helium production project in France, located in the south of the Nièvre department (See Fig. 1). Initial research and field measurements have revealed a high potential for He to be naturally released at the surface along with Carbon Dioxide through gaseous sources and a major geological fault in the area. The He content of this deposit would be sufficiently high to justify a financially viable exploitation. He is a strategic resource because this gas was produced in only a few countries in 2016, including the United States, Algeria, Australia, Poland, Qatar, and Russia.<sup>2</sup> Indeed, He represents an irreplaceable resource in various applications, such as medical imaging devices, or the manufacture of electronic products (Häussinger et al., 2001). On the other hand, CO<sub>2</sub> can also be valorized through these industrial uses, for example for carbonate or bioenergy production (Meylan et al., 2015). An application for an Exclusive Research Permit<sup>3</sup> (ERP) covering twelve municipalities, with an area of 251 km<sup>2</sup> was filed on October 19, 2019, and obtained on June 3, 2021. The company’s objective is to move from a pilot unit in 2023 to industrial-scale production by 2027. As soon as the ERP was obtained, 45-8 Energy took the decision to communicate widely on the project about potential risk to all the stakeholders (i.e., leaflet, publications in the press, publications on social networks or even presence in the twelve municipalities of the ERP).

### 1.2. Aim of the study

This exploratory study aims to understand how social and psychological anchors impact the way stakeholders will perceive the risks associated with objects (i.e., He and CO<sub>2</sub>). To achieve this objective, in accordance with the methodologies stemming from the theory of social representations (Moliner and Lo Monaco, 2017), an analysis of the stakeholders’ perceptions of HE and CO<sub>2</sub> will be conducted. Considering the theoretical elements presented and used in the literature to analyze risk perception, five points seem fundamental to structure these risks: (1) social determinants (i.e., socio-professional categories), (2) information delivered by the media, i.e., specific knowledge about each object, (3) attitude judgment towards objects, (4) general environmental

attitude and (5) proximity with the project. Thus, as suggested by Tan et al. (2019), in order to make a distinction in terms of proximity and direct experience with the project, the perceptions of two territories (approximately 30 km apart) were studied: (1) the residents of the twelve municipalities<sup>4</sup> of the ERP and (2) the residents of Nevers, a neighboring city but not directly concerned by the project. It is assumed that perceptions will be affected by the identified psychological and social dimensions and by geographic proximity to the project. This exploratory study could contribute to the literature on stakeholder analysis in projects and could be a new way to understand stakeholder risk perceptions in energy transition projects.

## 2. Méthod

### 2.1. Participants and procedure

To study the stakeholders’ perceptions of He and CO<sub>2</sub> of the project “Fonts bouillants” the services of a marketing research and opinion survey company (Harrys Interactive<sup>®</sup>), which uses quota sampling, were retained. This allowed us to ensure access to the target populations of the study while constituting a sample as close as possible to the socio-professional distribution observed in the population of the Nièvre department.<sup>5</sup> Thus, a telephone survey lasting an average of 15 min per participant was conducted in September 2021 among 306 residents of two geographical areas ( $M_{age} = 53.4$ ,  $SD_{age} = 16.2$ , 43% of women, see Table 1 for a detailed description of the sample). The first zone covered the twelve municipalities concerned by the exclusive research permit (ERP) for the “Fonts Bouillants” project and the second, targeted the town of Nevers not concerned by the project but close to the exploration zone. The residents of the ERP area ( $N = 142$ ,  $M_{age} = 51.5$ ,  $SD_{age} = 14.9$ , 38% of women) and the residents of Nevers ( $N = 164$ ,  $M_{age} = 55.0$ ,  $SD_{age} = 17.2$ , 47% of women) answered an interview consisting of 26-items integrating qualitative and quantitative methods assessing different psychological dimension in accordance with our research objectives. Thus, the participants could answer orally to the different parts of the interview: evocation task aimed at identifying the perceptions of individuals, attitude scales to collect evaluative judgment on each object, questions to assess knowledge of He and carbon dioxide (CO<sub>2</sub>) and finally a scale to measure the general attitude towards the environment.

### 2.2. Measures

#### Perceptions of Carbon dioxide and Helium.

Perceptions were collected using two free association tasks (e.g. Moliner and Lo Monaco (2017)), the method allows individuals to freely associate the words or expressions that come to their mind when they hear an inducing word. The first question was “What are the four words or expressions that come to your mind when someone says “Helium”?” and the second was “What are the four words or expressions that come to your mind when someone says “Carbon Dioxide or CO<sub>2</sub>”?”. The collected evocations were categorized by the authors, independently, and using classical rules of content analysis (Di Giacomo, 1980; Lambert et al., 2009; Rosenberg and Jones, 1972).

<sup>2</sup> <https://www.usgs.gov/media/files/helium-2016-pdf>.

<sup>3</sup> This exploration permit, issued by the French government for one or more specific resources, for a defined area and a limited period of time. Guarantees exclusivity of exploration to the company holding it over the defined period. Ensures that the company has the required skills, fulfills its commitments and respects the environment in which it operates.

<sup>4</sup> Azy-le-Vif; Chantenay-Saint-Imbert; Chevenon; Dornes; Luthenay-Uxeloup; Magny-Cours; Neuville-les-Decize; Saint-Parize-en-Viry; Saint-Parize-le-Châtel; Saint-Pierre-le-Moûtier; Sermoise-sur-Loire; Toury-sur-Jour.

<sup>5</sup> In 2019 : Farmers 1.8%, Artisans–Merchants and Business leaders 3.1%, Senior Managers–Liberal Professions 4.3%, Intermediate professions 10.6%, Employees 14.5%, Workers 12.3%, Retired 39.0%, Inactive 14.3%.

**Table 1**  
Characteristics of the participants, means and standard deviations for each variable.

Variables	Overall (n = 306)	ERP (n = 142)	Nevers (n = 164)
Age in year	53.4 (16.2)	51.5 (14.9)	55.0 (17.2)
<b>Gender</b>			
Men	174	88	86
Women	132	54	78
<b>Social professional category</b>			
Artisans–Merchants and Business leaders	13	8	5
Employees	39	18	21
Intermediate professions	55	30	25
Retired	106	39	67
Senior managers–Liberal professions	19	11	8
Workers	32	19	13
Farmers	5	5	0
Inactive	37	12	25
<b>Attitudes towards He</b>	4.71 (1.54)	4.88 (1.50)	4.57 (1.56)
<b>Attitudes towards CO<sub>2</sub></b>	3.29 (1.95)	3.49 (1.99)	3.11 (1.91)
<b>He knowledge score</b>	19.7 (6.03)	20.8 (5.77)	18.8 (6.11)
<b>CO<sub>2</sub> Knowledge score</b>	22.1 (6.42)	23.0 (6.46)	21.4 (6.31)
<b>Environmental attitude</b>	4.77 (1.06)	4.67 (1.07)	4.85 (1.05)

### Attitudes of Carbon dioxide and Helium.

Attitude, is defined as an evaluative judgment about a target such as an object, a person, a group, or an abstract idea (Albarracín and Johnson, 2018). In order to take into account, the limited time required for the telephone interview, the general attitude towards the objects “He” and “CO<sub>2</sub>” was measured with a single item (respectively: “In general, when you think of Helium, is your judgment completely negative or completely positive?” and “In general, when you think of carbon dioxide or CO<sub>2</sub>, is your judgment completely negative or completely positive?” A scale covering the entire attitude dimension was used explicitly to improve reliability and validity of the questions (Albarracín and Johnson, 2018). Thus, respondents were asked to position themselves verbally on a 7-point Likert scale ranging from 1 (= totally negative) to 7 (= totally positive).

### Knowledge of Carbon dioxide and Helium.

The knowledge questionnaire was based on the first communications disseminated during the public consultation for the exclusive research permit. An analysis of a corpus consisting of press articles, flyers distributed by 45-8 or interviews on local television (selected between 2018 and the end of 2020) was performed using IRaMuTeQ<sup>®</sup> software. A hierarchical classification allowed us to highlight 5 classes of discourse. They cover, for example, issues inherent to the import of He and CO<sub>2</sub> or the negative effects of imports on the environment. All these elements were taken into account in order to elaborate a knowledge questionnaire. Five knowledge items were created for He (e.g., “The demand for Helium is greater than its production”) and five knowledge items for CO<sub>2</sub> (e.g., “Carbon dioxide or CO<sub>2</sub>, is a flammable gas” (R<sup>6</sup>)). Participants were asked to position themselves verbally on a scale ranging from 1 (certainly false) to 7 (certainly true). The total score from 1 to 35 gives the level of knowledge about each object for each participant (see Appendices to see all the items).

### Environmental Attitude.

Environmental attitude was measured using the 12-item Environmental Attitude Inventory (EAI Milfont and Duckitt, 2010). For this study the French language validated version by Mousaoui et al. (2016) was used. In this study, the theoretical 1-factor EAI 12-item model did not fit the data  $\chi^2(43) = 50.1, p = .009, CFI TLI = .87, SRMR = .05, RMSEA = .02, 90\% CI [.00, .04]$ .

<sup>6</sup> Reversed item for which a high score indicates the opposite of the evaluated construct.

However, a one-factor model composed of 5 items, showed a better fit to the data  $\chi^2(5) = 9.51, p = .089, CFI = .94, TLI = .88, SRMR = .03, RMSEA = .05, 90\% CI [.00, .10]$ . In this model, 7 items were removed from the original scale. The Cronbach's alpha of the 5 retained items is .51, so internal consistency in our sample is acceptable (Taber, 2018).

### 2.3. Data analysis

Data were analyzed using JAMOVI<sup>®</sup> (version 2.3), R<sup>®</sup> (version 4.1.) and Rcommander<sup>®</sup> (version 2.8-0). To study the structuring of perceptions, two factorial correspondence analyses were performed (Moliner and Lo Monaco, 2017). This descriptive analysis allows to project on a bidimensional axis the semantic content collected through the evocation tasks according to different numerical variables (e.g., participant's attitude score). Thus, in accordance with the recommendations of Deschamps (Deschamps, 2005), the evocations whose frequency was greater than or equal to 4 for He and 8 for Carbon dioxide were selected. The relationship of these evocations was studied with several variables: place of residence (ERP municipalities, Nevers), attitudes towards He and CO<sub>2</sub>, knowledge towards He and CO<sub>2</sub>, environmental attitude and socio-professional categories (SCP+; SCP-; Inactives). For each measure, “low” and “high” classes were defined with a median split.

Finally, Student's *t*-test were used to examine whether there was a significant difference between residents of the ERP municipalities and residents of Nevers in their environmental attitudes, knowledge and attitudes towards He and CO<sub>2</sub>.

## 3. Results

### 3.1. Perceptions of Helium

#### Structure description of the Helium object.

The corpus was composed of productions from 306 participants. In total, for all the participants, 704 verbal associations were collected as some participants did not provide the 4 words expected. Once the corpus had been cleaned, 658 different semantic units were obtained (See Appendix B for the frequencies of the different categories).

The CORR. F. A. highlights two factors that explain 61.75% of the table's inertia (Factor 1 = 39.68%; Factor 2 = 22.07%). Factor 1 receives a contribution from the terms of the variable “Socio-Professional Category”: CF (SPC+) = .12, “Attitude towards Helium”: CF (Att.High) = .9 + CF (Att.Low) = .11, and

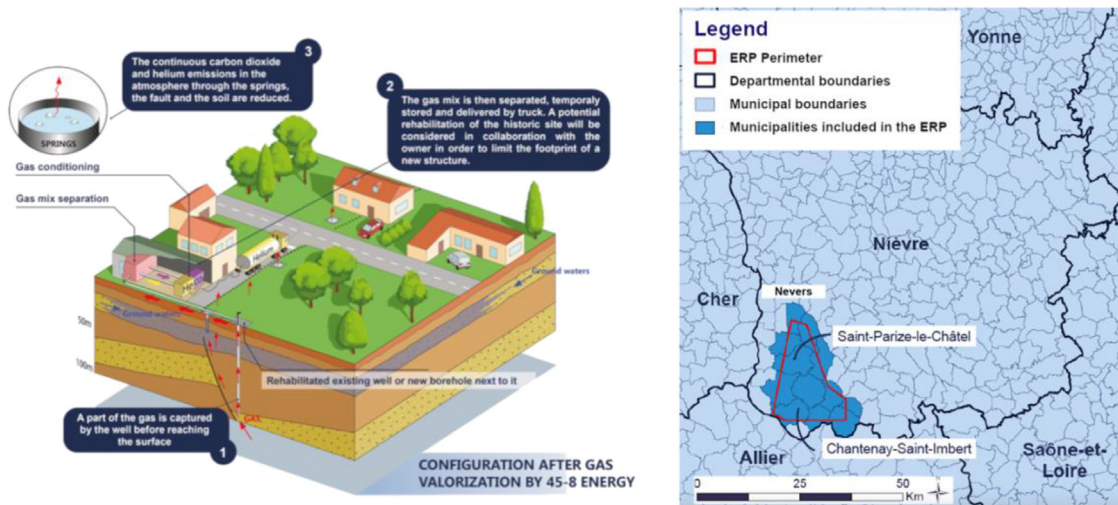


Fig. 1. Presentation of the perimeter of the “Fonts-Bouillants” project for the valorization of Helium and Carbon dioxide.

“Territories”:  $CF(\text{Nevers}) = .17 + CF(\text{ERP}) = .18$ , i.e., a contribution of 67%, to the formation of the factor. Factor 2 receives a contribution from the terms of the variable “Socio-Professional Category”:  $CF(\text{SPC-}) = .21 + CF(\text{Inactive}) = .21$ , “Helium Knowledge”:  $CF(\text{High Knowledge}) = .11 + CF(\text{Low Knowledge}) = .16$ , “Territories”  $CF(\text{Nevers}) = .9 + CF(\text{ERP}) = .10$ , i.e., a contribution of 88%, to the formation of the factor. Fig. 2 shows this configuration.

The horizontal axis (factor 1) is structured by opposing individuals based on territory, attitudes, and high socio-professional category. Factor 1 shows that participants from the 12 municipalities covered by the ERP, participants with high SPC, and

participants with high attitude differ from the perceptions of participants from Nevers and participants with low attitude. Indeed, the former (ERP, SCP+, Att.HE.High) associate He with the most well-known use of He by using the term *Party*. They also evoke the mental state that could result from the absorption of He with the term *Euphoria* (even though these individuals seem to amalgamate the consequences related to nitrous oxide with He). These are also the participants who are most aware that He is an *Energy* and that this gas is *Rare*. These participants are therefore the most conscious of the issues inherent in the exploitation of He. On the right side of the axis (factor 1), participants from Nevers, and participants with a low attitude towards He. These participants mention descriptive elements related to the properties of this gas

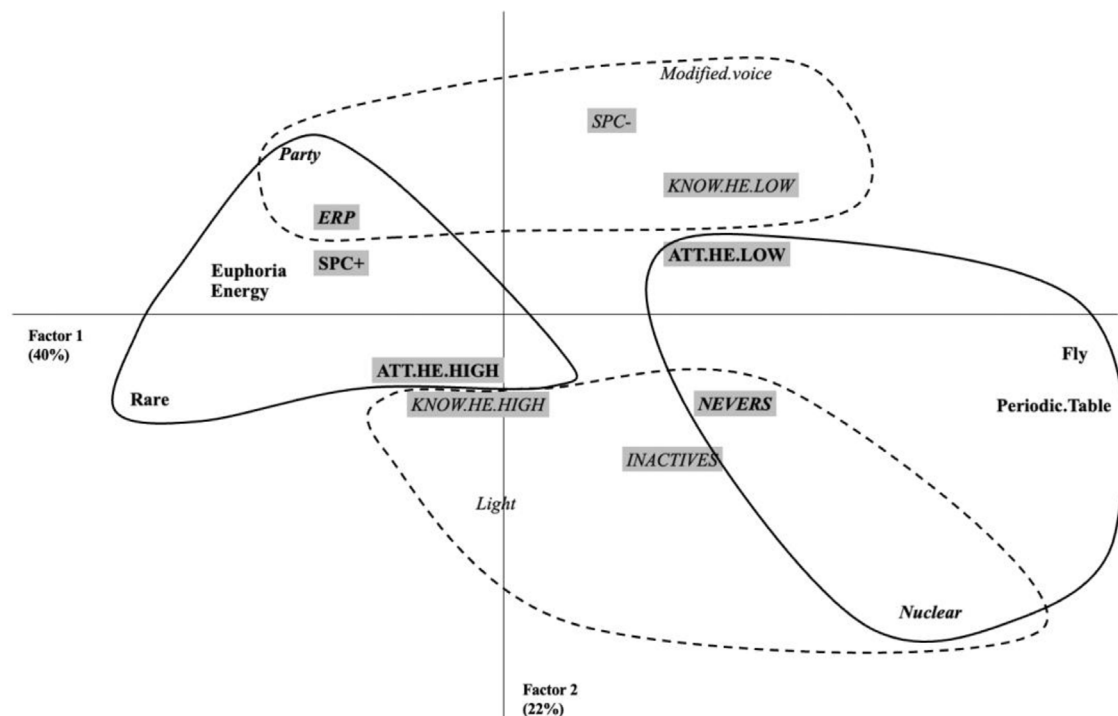


Fig. 2. Graphical representation of the results produced by the factorial correspondence analysis for Factor 1 and 2 concerning the Helium inducing term. Note: Shaded blocks refer to experimental conditions. The “variables and measures” contribute to the formation of Factor 1; the “variables and measures” refer to the variables and measures that contribute to the formation of Factors 1 and 2. “Perceptions” refers to perceptions that contribute to the formation of Factor 1; “Perceptions” refers to perceptions that contribute to the formation of Factor 2; “Perceptions” refers to perceptions that contribute to the formation of both Factors 1 and 2.

such as *Fly* or associate He with its chemical component with the idea of the *Periodic Table*.

The vertical axis (factor 2) opposes the participants according to their knowledge of He and their socio-professional categories. Participants with low knowledge of He and participants with low socio-professional categories refer to the most known consequence of He as *Modified Voice*. On the other side of the axis, inactive participants and participants with high knowledge towards He will each refer to an effect related to He use with the term *Light*. These participants are also the ones who most associate He with *Nuclear*.

Structure analysis of the Helium object

The results of the C.F.A. suggest an organization of perceptions associated with helium that is influenced by several factors. First of all, the variable “territory” seems to determine the participants’ discourse on this object. Compared to the residents of Nevers, the residents of the towns in the ERP already associate this object with the idea that helium could eventually constitute an “energy” that could be mobilized in the context of the energy transition. They are also more likely to think that this energy is “rare” and therefore needs to be valued. The presence of these ideas in the discourse of the ERP residents is perhaps linked to communications or to the presence of the company in the territory, which may have facilitated the structuring of the object as a potential energy. Another important factor in the constitution of the axes is the level of knowledge of the participants. Participants with a low level of knowledge about helium focused on the idea of festivity (e.g. “party”; “modified voice”). For these participants, helium is at no point understood as potential energy. In general, perceptions of helium are particularly descriptive and mention very little evidence of the idea of risk associated with its use.

3.2. Perceptions of CO<sub>2</sub>

Structure description of the CO<sub>2</sub> object

The corpus was composed of productions from 306 participants. In total, for all the participants, 758 verbal associations were collected as some participants did not provide the 4 words expected. Once the corpus had been cleaned, 723 different semantic units were obtained (See Appendix C for the frequencies of the different categories).

The CORR. F. A. highlights two factors that explain 67.72% of the table’s inertia (Factor 1 = 42.38%; Factor 2 = 25.34%). Factor 1 receives a contribution from the terms of the variable “Socio-Professional Category”: CF (SPC-) = .12 + CF (Inactive) = .27, “Attitude towards CO<sub>2</sub>”: CF (Att.Low) = .11, and “Knowledge CO<sub>2</sub>”: CF (High. Knowledge) = .10 + CF (Low. Knowledge) = .11, i.e., a contribution of 71%, to the formation of the factor. Factor 2 receives a contribution from the terms of the variable “Socio-Professional Category”: CF (SPC-) = .22 + CF (SPC+) = .14, “Attitude towards CO<sub>2</sub>”: CF (Att.High) = .13 + CF (Att.Low) = .16, and “Environmental Attitude”: CF (Att.Env.Low) = .11, i.e., a contribution of 76%, to the formation of the factor. Fig. 3 shows this configuration.

The horizontal axis (factor 1) is structured by opposing individuals based on their knowledge, socio-professional categories, and attitudes towards CO<sub>2</sub>. Factor 1 shows that the perceptions of inactive, participants with low attitudes towards CO<sub>2</sub> and participants with low knowledge differ from the perceptions of participants with high knowledge and participants with low socio-professional categories. Indeed, the former (i.e., INACTIVE, Att.CO2.High, Know.CO2.Low) associate CO<sub>2</sub> with a use related to CO<sub>2</sub> emissions *Car*. These participants also evoke the notion of risk for the *Planet* through the evocations *Danger* and *Pollution*. On the right side of the axis (factor 1), participants with low SCP who evoke descriptive elements such as *Oxygen*, *Air* and *Breathe*.

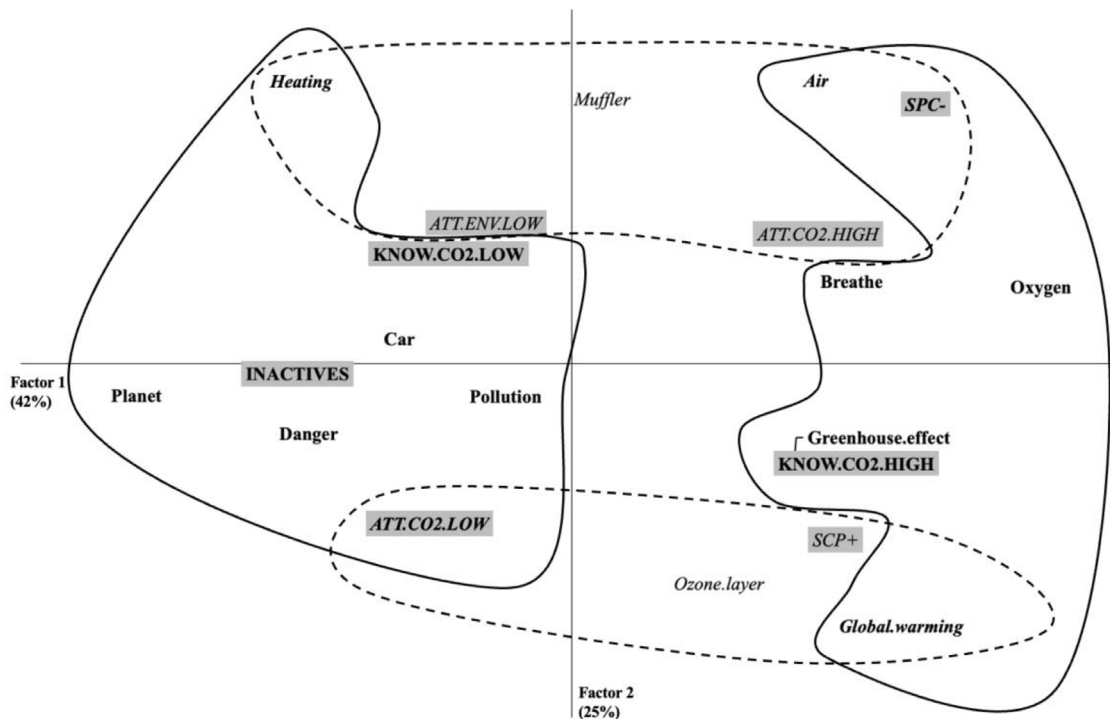


Fig. 3. Graphical representation of the results produced by the factorial correspondence analysis for Factor 1 and 2 concerning the CO<sub>2</sub> inducing term. Note: Shaded blocks refer to experimental conditions. The “variables and measures” contribute to the formation of Factor 1; the “variables and measures” refer to the variables and measures that contribute to the formation of Factor 2; the “variables and measures” refer to the variables and measures that contribute to the formation of Factors 1 and 2. “Perceptions” refers to perceptions that contribute to the formation of Factor 1; “Perceptions” refers to perceptions that contribute to the formation of Factor 2; “Perceptions” refers to perceptions that contribute to the formation of both Factors 1 and 2.

**Table 2**  
Comparison of attitude and knowledge about Helium and CO<sub>2</sub> and environmental attitude based on territory (Independent Samples t-Test).

Dimension	Territories	M	Mean difference	SE difference	df	t	p	Cohen's d
Attitudes Helium	ERP	4.88	-.319	.178	296	-1.79	.037	-.208
	Nevers	4.57						
Attitudes towards CO <sub>2</sub>	ERP	3.49	-.382	.224	301	-1.71	.044	-.197
	Nevers	3.11						
Knowledge about Helium	ERP	20.8	-2.004	.682	304	-2.94	.002	-.337
	Nevers	18.8						
Knowledge about CO <sub>2</sub>	ERP	23.0	-1.552	.732	304	-2.12	.017	-.243
	Nevers	21.4						
Environmental attitudes	ERP	4.67	0.175	.122	303	1.44	.151	.165
	Nevers	4.85						

The participants with the highest knowledge associate CO<sub>2</sub> with the consequences that this gas can have, they use the terms *Greenhouse effect* and *Global warming*.

The vertical axis (factor 2) opposes participants based on their socio-professional categories, environmental attitudes, and attitudes towards CO<sub>2</sub>. Participants with low environmental attitudes, participants with low SCP, and participants with high attitudes towards CO<sub>2</sub> refer to CO<sub>2</sub> emissions using the terms *Heating* and *Muffler*. On the other side of the axis, participants with higher socio-professional categories and participants with low attitudes towards CO<sub>2</sub> will each refer to the effects of CO<sub>2</sub> emissions using the term *Ozone Layer*.

#### Structure analysis of the CO<sub>2</sub> object

The results of the C.F.A. suggest that participants' discourse is organized around the notion of risk and particularly the impact of CO<sub>2</sub> emissions on the environment. For this object well known to the general public, contrary to helium, it seems that the territory variable does not structure people's perceptions of CO<sub>2</sub>. However, several positions coexist and are linked to different social anchors. The factor related to environmental attitudes influences the participants' discourse (which was not the case for helium). Specifically, people with pro-environmental attitudes point out the danger of CO<sub>2</sub> emissions to the climate (e.g., "*climate change*", "*ozone layer*"). Conversely, people with less pro-environmental attitudes mention particularly descriptive items, indicating less involvement with the topic. As these results show, the dissemination of future messages on the possible valuations of CO<sub>2</sub> could run up against the filters constituted by the knowledge, ideologies of individuals and groups. However, these elements filter the information to make it compatible with the already existing systems of representations.

#### 3.3. Attitudes, knowledge towards Helium and Carbon dioxide and environmental attitudes

Analysis of the results show that compared to the residents of Nevers, the residents of the 12 municipalities of the ERP have more positive attitudes towards He and CO<sub>2</sub>. Similarly, participants from the ERP municipalities have a higher knowledge about He and CO<sub>2</sub> than participants from Nevers. On the other hand, the results do not show significant differences in environmental attitudes between the residents of the two territories (see Table 2).

## 4. Discussion

The objective of this study was to understand how social and psychological anchors impact the way stakeholders perceive risks in the French context of a project aiming to valorize two gases: Helium and Carbon Dioxide. In accordance with our objectives, the results of these studies show how individuals from two territories, one geographically concerned and the other not

concerned by the project, structured their perceptions of these two gases. The results of this study show that there are differences in attitudes and knowledge about the objects between these two territories. The participants of the ERP municipalities are, compared to the residents of Nevers, more positive towards the two gases and have a better knowledge. However, these two territories do not differ in terms of environmental attitudes.

Three results are to be retained and seem to deserve some elements of explanation, as geographical and socio-professional belonging play their importance in the structuring of the representations relating to the two studied gases. The main results of the study show that: (1) while the representation of He is structured by geographical affiliation, the representation of CO<sub>2</sub> is not. Residents near the ERP area have more precise representations of He (e.g., they evoke ideas conveyed by the communication such as *Energy*) than residents of Nevers (e.g., these participants mention descriptive elements of He), (2) on the other hand, the representation of CO<sub>2</sub> is structured mainly by the participants' social anchorage: the high socio-professional categories are better informed than the low socio-professional categories, leading the former to have a more detailed knowledge of the consequences of an excess of CO<sub>2</sub> (e.g., *Global warming*) compared to the latter; (3) if the risk is used to talk about CO<sub>2</sub> (e.g., *Danger*; *Pollution*), it is not mentioned for He which remains a relatively unknown gas about which the participants remain relatively descriptive (e.g., the festive uses of gas).

These three main results seem to be related to participants' initial attitudinal judgments and the way they received information towards the two gases. Indeed, He, which is mostly known for its festive aspects, was on average judged more positively by participants. On the other hand, CO<sub>2</sub>, which is a topic that is strongly debated in the media, about the risks related to the consequences of climate change, was judged much more negatively. Secondly, the distribution channels were different in the two territories. The participants in Nevers received information indirectly (e.g., press), whereas the participants in the 12 municipalities of the ERP also received direct information through the presence of the company on the site. Thus, in the case of He, direct and indirect communication in the area of the ERP was able to rely on a favorable attitude and facilitate the consideration of the information. However, for CO<sub>2</sub>, the individuals have knowledge marked by the notion of risk. The initial negative attitude did not favor the consideration of the communication. In this case, the expression of perceptions was mainly based on the anchors of the individuals. Indeed, these differences may be due to participants' strong attitudes both positive and negative, as an individual resists risk more easily when his or her attitude is strong (Fagnot and Stanton, 2015).

In this study, He and CO<sub>2</sub> are characterized by relatively strong positive and negative attitudes. These strong attitudes are known to persist over time, resist change, and influence cognitions (e.g., Fazio (1995) and Krosnick and Smith (1994)), which would explain why the two gases have different statuses in



participants' perceptions. According to Doise (1990) social representations are constructed through two processes: objectification and anchoring. Objectification aims to transform an abstract object to make it concrete, and anchoring allows the object to be integrated into the pre-existing thought system (Moliner, 2015). Here, carbon dioxide shows a real diversity in terms of content, particularly because this object has been at the heart of the debate on the negative consequences of global warming for several years. This has certainly allowed the participants to objectify and anchor their perceptions of CO<sub>2</sub> in a pre-existing thought system based on the notion of risk. Thus, each of the subgroups (e.g., socio-professional categories) was able to express their perceptions of the risks of CO<sub>2</sub>, from the least elaborate (e.g., *Heating*) to the most elaborate (e.g., *Greenhouse effect*). He, on the other hand, is an object that is little known by the general public for its industrial uses, but is known above all for its festive uses. Therefore, the participants have objectified and anchored their perceptions on this pre-existing thought system that is free of the notion of risk. In this case, He, which is not very influenced by social anchors, was able to let the territory variable structure the perceptions of the individuals.

At this early stage of the project, it appears that the direct and indirect communication offered by the company may have affected the sense of trust. Indeed, direct communication for the 12 ERP municipalities may have facilitated the establishment of a climate of trust often considered important for subsurface project implementation (Terwel et al., 2011) and for the decision-making process (Dütschke, 2011). Moreover, the relationship is not only one-way, as numerous research studies have highlighted the beneficial effects of knowledge appropriation on the establishment of a climate of trust (Beratan, 2007). Indeed, the company's presence on the field was able to generate more trust by communicating arguments that were congruent with the company's values and objectives (e.g., eco-responsible production) and by making it known that the various stakeholders had a voice in the decision-making process (Barbier et al., 2020). Thus, this established trust must be maintained throughout the process, particularly because it is an important factor in explaining the perception of technologies (Tcvetkov et al., 2019). Indeed, in this type of project when an object is not yet charged with particular affect or when it is, it seems imperative to apprehend each of the interactions with all the stakeholders in full transparency so that the debate really takes place. Thus, as Chailleux and Arnauld De Sartre (Chailleux and de Sartre, 2021) suggest, the decision-making process would no longer be confined to the discussion arenas of specialists and promoters, but would be the responsibility of all and would eventually lead to a true "politicization" of the debate.

Finally, in this study, the notion of risk is used to talk about CO<sub>2</sub>, whereas it is not used to talk about He. The concept of social amplification of risk (Kasperson et al., 1988) may be instructive in understanding the differences in perception between these two gases. In the first case, CO<sub>2</sub>-related events such as global warming, pollution are plentiful in the media (e.g., television, radio, newspapers, social networks, etc.). These media have served as an "amplification station" (Kasperson et al., 1988) and have probably generated many debates in society, with family and friends. Thus, beyond the people directly affected by the initial event reported in the media, these debates and behaviors related to risk have probably had a ripple effect and have contributed to the social construction of risk in relation to this object. Thus, whatever the social and psychological background of the individuals, their perceptions are marked by the notion of risk. Conversely, He remains a relatively unknown gas, except for its festive uses. This gas is therefore not the subject of specific discussions in the media or in more restricted circles on its potential health hazards (e.g., asphyxiation in case of significant inhalation). This

again shows the influence of psychological and social anchors on the construction of risk (Slovic, 1999). The differences in risk perception between these two gases show, especially in the case of CO<sub>2</sub>, the extent to which individuals try to make sense of the events they are or will be facing (Mezirow, 1991). More generally, this differentiated perception of risk will, in the case of negatively perceived CO<sub>2</sub>, influence individual adaptation strategies for example through learning processes related to past events (Bubeck et al., 2012; Collenteur et al., 2015).

The results of this study provide levers for designing and adjusting the communications proposed by a company developing a project. One possible solution would be to rely on the principles of the inoculation theory (McGuire, 1964; Wood, 2007) so that individuals are: (1) alerted and informed about the risks of a project; (2) exposed to counter-arguments to their perceptions; (3) provided with new communications in the form of refutations so that they can resist the hazards that may arise. Thus, in the case of an object without prior structuring, the challenge is to make sure that through communication one can bring enough elements of knowledge towards He so that these elements can continue to build the perception of He more than the social anchors. As He is not totally influenced by social anchors, the development of knowledge, which brings information describing precisely the extraction of He, provides them with arguments to counteract attempts of influences that may occur during the extraction (e.g., seismicity related to drilling). On the contrary, in the case of an object with a strong prior structuring. The challenge is to ensure that the social anchors are used to communicate in an appropriate manner on each of the risks raised in the perceptions of individuals. Thus, the communication must provide sufficient elements explaining the interest of exploiting (i.e., capturing; valorizing) CO<sub>2</sub> for example to reduce the negative impacts of CO<sub>2</sub> emissions (e.g., *global warming*). The idea is that these elements must, according to the particularities of the stakeholders, build a particular representation at the territory scale. As CO<sub>2</sub> is influenced by social anchors, the development of knowledge, which provides information on the usefulness of CO<sub>2</sub> exploitation, provides them as well as the He with arguments to counteract attempts to influence the extraction.

However, these studies have some limitations. First, the sample size did not allow us to explore perceptions within the 12 municipalities covered by the exclusive research permit. This could have allowed us to assess the existence of differences that might exist within the territory itself. Second, the time-constrained survey methodology forced us to make some choices that did not allow us to study the full range of psychological processes affecting risk, such as probability, susceptibility, and severity of risk (Brewer et al., 2007). Furthermore, this study only offers a snapshot at a specific moment in time, which does not allow us to explore the evolution of perceptions throughout the project. Future longitudinal research could study, through repeated measurements on the same individuals, the evolution of perceptions throughout a project to continuously adapt communication within the debates. This would allow, on the one hand, to improve the understanding of the consultation process and, on the other hand, to provide the resources to accompany the development of knowledge and the evolution of attitudes throughout the course of a project.

## 5. Conclusion

Transversal methodologies associated with the theory of social representations could contribute to the vast field of literature dedicated to the analysis of stakeholders in projects. The intervention tools used in this study can constitute new methods of analysis and characterization of the stakeholders in order to

**Table 3**  
Participant’s evocations of the word “Hélium” as a function of variables.

	Freq	SCP-	SCP+	Inactive	Att.He high	Att.HE low	Knowledge He high	Knowledge He low	Att.Env high	Att.Env low	Nevers	ERP
Gas	182	42	57	82	98	83	109	72	102	79	95	86
Balloon	136	37	38	60	68	67	76	59	74	61	70	65
Light	46	6	18	21	25	20	33	12	22	23	30	15
Hot-Air Balloon	44	11	14	18	22	21	21	22	27	16	22	21
Air	24	6	8	9	12	11	16	7	11	12	11	12
Modified voice	22	9	9	4	8	14	10	12	13	9	13	9
Party	19	2	8	8	7	11	9	9	7	11	3	15
Euphoria	17	5	7	4	11	5	12	4	9	7	6	10
Energy	15	3	8	4	11	4	10	5	9	6	6	9
Physics-Chemistry	13	2	5	5	7	5	6	6	6	6	7	5
Rare	7	1	3	3	4	3	6	1	3	4	2	5
Flight	7	1	1	5	1	6	3	4	5	2	5	2
Periodic table	7	2	1	3	2	4	3	3	4	2	6	0
Nuclear	5	0	0	5	2	3	3	2	4	1	3	2
Pollution	5	1	2	2	2	3	2	3	4	1	3	2
Sun	4	0	1	3	3	1	2	2	1	3	2	2

**Table 4**  
Participant’s evocations of the word “CO<sub>2</sub>” as a function of variables.

	Freq	SCP-	SCP+	Inactive	Att.He high	Atti.HE low	Knowledge He high	Knowledge He low	Att.Env high	Att.Env low	Nevers	ERP
Pollution	135	25	44	66	63	72	61	74	76	59	67	68
Gas	44	10	14	20	26	18	22	22	23	21	27	17
Breathe	36	14	13	9	25	11	20	16	23	13	20	16
Greenhouse effect	28	6	14	8	17	11	20	8	17	11	17	11
Global warming	28	4	16	8	15	13	20	8	24	4	15	13
Plant	25	7	7	8	16	6	14	8	13	9	11	11
Toxic	22	5	5	12	12	10	9	13	11	11	8	14
Car	22	5	5	12	9	13	10	12	10	12	12	10
Air	21	10	5	6	18	3	9	12	12	9	13	8
Danger	20	1	6	13	8	12	8	12	10	10	10	10
Oxygen	17	9	5	3	12	5	13	4	12	5	11	6
Emission	16	3	7	4	10	4	6	8	6	8	7	7
Ecology	12	2	1	9	6	6	7	5	6	6	9	3
Asphyxiation	12	3	3	6	8	4	8	4	7	5	6	6
Environment	11	3	5	3	6	5	5	6	7	4	6	5
Combustion	11	1	4	6	6	5	9	2	6	5	6	5
Ozone layer	11	4	4	3	3	8	6	5	10	1	3	8
Heating	10	4	0	6	5	5	2	8	4	6	5	5
Planet	10	0	1	9	4	6	3	7	6	4	7	3
Muffler	9	3	2	4	7	2	4	5	3	6	4	5
Carbon	8	0	3	5	5	3	6	2	5	3	5	3
Death	8	3	2	3	1	7	5	3	5	3	4	4
Atmosphere	8	1	1	6	5	3	4	4	6	2	5	3

objectify the structuring of the perceptions of a large number of stakeholders by taking into account the psycho-social anchors (e.g., geographical affiliation, knowledge, social affiliation and psychological positioning).

Finally, providing information about a project in a totally transparent way seems to be an essential part in the realization of these projects. Information should not seek to structure perceptions or attitudes at all costs, but should, according to these two measures, structure the information to make it accessible to all. The idea in the end is to provide knowledge likely to allow everyone to debate on the basis of information shared by all the stakeholders and to allow the establishment of a climate of trust that seems necessary for the decision-making process in subsurface projects.

**CRedit authorship contribution statement**

**Kévin Nadarajah:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Stéphanie Bordel:** Validation, Writing – review & editing. **Jean-Charles David:** Validation, Writing – review & editing. **Laurent Jammes:** Validation, Writing –

review & editing. **Gilles-Laurent Rayssac:** Validation, Writing – review & editing. **Alain Somat:** Validation, Writing – review & editing.

**Declaration of competing interest**

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

**Data availability**

Data will be made available on request.

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## Informed consent statement

The study was conducted according to the guidelines of the Declaration of Helsinki; an informed consent was obtained from all participants involved in the study.

## Appendix A. Knowledge questionnaire

### Knowledge items for Helium

Helium capture is expensive.  
Helium is an inexhaustible resource (R).  
Helium escapes from the ground into the atmosphere.  
The demand for helium is greater than its production.  
The capture of helium requires indirect and environmentally friendly techniques.

### Knowledge items for Carbon Dioxide

Carbon dioxide or CO<sub>2</sub> is naturally produced by the planet.  
The capture of carbon dioxide or CO<sub>2</sub>, has adverse effects on global warming (R).  
Carbon dioxide, or CO<sub>2</sub>, is used to fight fires.  
Carbon dioxide, or CO<sub>2</sub>, is used by the food industry.  
Carbon dioxide or CO<sub>2</sub>, is a flammable gas (R).

## Appendix B

See Table 3.

## Appendix C

See Table 4.

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