Risk Communication and the Role of Scientists in Raising Awareness in the Field of Public Health: The Case of Radon Gas

Comunicación de Riesgo y el Papel de los Científicos en la Sensibilización sobre Salud Pública: El Caso del Gas Radón

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Risk Communication; Public Health; Scientist, Radon, Environmental Communication

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Comunicación de Riesgos; Salud Pública; Científico; Radón; Comunicación Ambiental

ABSTRACT
Nowadays, effective communication of health risks is crucial. Factors like risk perception, message complexity, and strategies shape its public health impact. This study examines the role of Spain's scientific community in raising awareness about the persistent and widespread risk of radon gas. Semi-structured interviews with experts highlight the urgent need for improved radon gas communication in Spain. Scientists encounter challenges in conveying technical information to a population with limited understanding of radon and its effects. Collaboration between media and public administration is essential, necessitating increased media coverage and public awareness efforts. Targeted segmentation proves effective, with potential yet to be fully realized in digitalization and social media platforms. However, communication must balance utility and responsibility, aiming to empower citizens to make informed decisions.

RESUMEN
Hoy en día, la comunicación efectiva de riesgo para la salud es crucial. Factores como la percepción del riesgo, la complejidad del mensaje y las estrategias empleadas determinan su impacto en la salud pública. Este estudio examina el papel de la comunidad científica en España en la sensibilización sobre el riesgo persistente y generalizado del gas radón. Entrevistas semiestructuradas con expertos ponen de relieve la necesidad urgente de mejorar la comunicación sobre el gas radón en España. Los científicos enfrentan desafíos a la hora de transmitir información técnica a una población con un conocimiento limitado sobre el radón y sus efectos. La colaboración entre los medios de comunicación y la administración pública es esencial, lo que requiere un aumento de la cobertura mediática y de los esfuerzos de concienciación pública. La segmentación dirigida resulta eficaz, con un potencial aún por explotar plenamente en la digitalización y las plataformas de redes sociales. Sin embargo, la comunicación debe equilibrar utilidad y responsabilidad, con el objetivo de empoderar a los ciudadanos para que tomen decisiones informadas.

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1. An introduction to risk communication

Our research focuses on risk communication, understood as risk management through communication among individuals, groups, and institutions regarding risk assessment, characterization, prevention, and resolution. Interest in risk communication has grown markedly in recent years, peaking in 2009 and steadily increasing since 2013. The COVID-19 pandemic has further increased its relevance. According to Web of Science (WOS), 46.7% of research on risk communication has been published in the last five years.

Leiss (1996) has examined risk communication since 1976 and identified three main phases: 1) emphasis on risk, involving precise risk management in a modern industrial economy; 2) emphasis on communication, where persuasive communication plays a central role in convincing receivers of a viewpoint considered to be correct; and 3) recognition by public and private institutions of their responsibility for effective communication and efforts to achieve the same.

Risk communication research is related to the goal of protecting the public from various threats, such as those related to health (Plough, 1987). Given its multidisciplinary nature, risk communication can leverage a wide range of knowledge and experiences, leading to a marked decentralization (McComas, 2006). In this sense, Bouder et al., (2012) emphasize the importance of interdisciplinary collaboration in generating high-quality information as the basis for communication.

Risk communication encompasses any exchange of information about health or environmental risks between governmental bodies, media, scientists, public interest groups, and citizens, among others (Covello et al., 1986). Research in the field seeks to understand and analyse people's decisions and behaviour in modern society in the face of threats (Renn, 2020). Two essential aspects of this communication are its focus on diverse audiences (Lang et al., 2001) and its adoption of multiple formats (Covello et al., 1988). Its main goal is to inform stakeholders about risks (National Research Council, 1989) and persuade them (Cho et al., 2015) to adopt self-protective behaviours that minimize potential adverse health effects (Lopez & Cho, 2021). Risk communication strategies should promote learning for both regulators and the public (Keeney & Von Winterfeldt, 1986).

Risk perception, understood as the subjective evaluation of a threat, guides cognitive, emotional, and behavioural responses to health-threatening conditions (Lopez & Cho, 2021). Understanding individual differences in perception and the information needs of various audiences and stakeholders facilitates the effective delivery of risk

information (Frewer, 2004). Thus, risk communication plays a crucial role in linking risk perception with risk management (Rohrmann, 2008).

Risk communication varies in its efficacy. As such, different people can perceive the same risk as an individual or collective risk, with many factors at play (So & Nabi, 2013). Among these, trust in the source of information plays a crucial role in influencing the message (Kasperson & Palmlund, 2012). University scientists are often perceived as a reliable source (Breakwell, 2000). However, credibility tends to be higher when a single viewpoint is presented instead of multiple conflicting ones (Kortenkamp & Basten, 2015). This paper analyses communication by scientists–an expert source–in a specific case study, that of radon gas.

Despite the risks radon poses to health, it is relatively simple to detect and mitigate. Consequently, apathy towards this risk is likely to decrease when people see that they can take concrete steps to reduce the risk on their own (Fisher, 1991). However, sometimes the public is more concerned about risks controlled by others than those requiring their own action to mitigate, as in the case of radon (Guimond & Page, 1992). The lack or inadequacy of information also influences how people perceive the severity of a risk (Griffin et al., 2004). Overly succinct information formats can lead to misunderstandings (Smith & Desvousges, 1990). Moreover, the population may not receive the information if inappropriate channels are used or if it is too complex. Understanding information can influence people's behaviour (Cori et al., 2022), and the complexity of the radon problem and regional context can vary (Golding et al., 1992).

Several factors affect the correlation between risk assessment and its acceptability, such as homogeneous versus random distribution, scientific consensus on the message, the existence of mitigation remedies, and the level of control affected individuals have (Covello et al., 1988). Moreover, the information received about a risk affects perceptions (Yoo, 2019), as do inherent risk variables such as naturalness, controllability, fairness, and familiarity (Sandman, 1987).

Though the object of study remains the same, technological, social, and health innovations have caused significant changes in risk communication. Twenty-six years ago, scholars suggested that risk communication was entering a new phase that would focus more on how social contexts may influence how people respond to information about risks (McComas, 2006). Today, it is crucial to consider risk communication 2.0 (Mora-Rodríguez & Melero-López, 2021) and the fourth wave of digital communication (García-Orosa, 2021).

Different groups, such as the elderly, respond differently to the same message (Johnson et al., 1988). Similar to people with lower levels of formal education, the

elderly are less likely to correctly process risk information (Smith et al., 1987). Culture or population can also be relevant factors for processing information (Kim et al., 2020). Furthermore, fear plays a determining role in how people react to a message. Greater evoked fear translates into lower acceptance of the message, which in turn produces a negative response (Meulenaer et al., 2015). This is especially important when a message is alarming, as it causes people to perceive a greater threat (Zhang & Zhou, 2019), triggering fear which in turn increases the intention to share these risk messages, which can have counterproductive effects (Couch et al., 2017).

The dissemination of strictly scientific information typically does not interest the general public (Denia, 2020; Pascual-Presa & Forja-Pena, 2024), and health-related information must be related to extreme positions in order to garner coverage (Thompson, 2019). Today, however, people are increasingly turning to websites, social media, and other digital media to obtain health-related information (Masilamani et al., 2020).

Social media allow for disseminating information to a wide variety of audiences (Strekalova & Krieger, 2017), which information can effect changes in public behaviour positively towards preventive attitudes in the face of a risk (Oh et al., 2021). They can also open new communication channels (Toppenberg-Pejcic et al., 2019) and significantly amplify the dissemination of health messages (Ali et al., 2019). Encouraging people to share information through their socials not only helps with this but is also a fundamental factor in leading people to take preventive actions in the face of risks (Lee et al., 2020).

Moreover, social networks can significantly help a news story go viral (Kim, 2015), in addition to reducing the cultural barriers that exist between users (Ems & Gonzales, 2016). Furthermore, they not only allow for the exchange of information but also facilitate the building of transparency and trust between the communicator and the public (Lambert, 2020). However, the use of social networks and the internet can have negative effects when a risk exists, such as the spread of misinformation (Huang & Wang, 2022). It should also be noted that, although internet users may be accustomed to receiving and processing a large amount of information, this large quantity can conceal or muddy the importance of a risk, causing it to go unnoticed (Guo & Li, 2018; Sixto-García et al., 2024). Other aspects, such as a person's familiarity with a particular platform, can be factors that affect their perception of the information disseminated thereon (Britt et al., 2023). In addition, people seek more information once they have received the message about the risk they face (So et al., 2019), although they will only turn to that communication channel if they take it to be reliable or credible (Hwang & Jeong, 2020). This is especially important for invisible risks such as radon (Skotnes et al., 2021).

2. The risk posed by radon gas

In this research, we will focus on a specific risk: radon gas. Its significance lies in its persistence over time and its deleterious effects on health demonstrated for nearly four decades, despite limited public knowledge about the seriousness of this risk (Khan & Chreim, 2019).

Radon gas has been recognized as a carcinogen by the World Health Organization's International Agency for Research on Cancer since 1988. In recent decades, it has been observed to be the leading cause of lung cancer in non-smokers. The proportion of lung cancer cases associated with radon varies from 3% to 14%, depending on the average radon concentration in the country and the calculation method used. However, radon is the leading cause of lung cancer in non-smokers and the second leading cause in smokers.

The primary source of population exposure to ionizing radiation is natural radon and its decay products. Due to its tasteless, odourless, and invisible nature, radon is undetectable without specific testing. Buildings constructed in areas with rock beds or soils rich in uranium can accumulate high concentrations of radon in the indoor air, posing a serious health threat (Villar, 2017). Radon seeps from the ground and can accumulate in enclosed spaces, particularly in homes and workplaces. Due to its higher density than air, it tends to concentrate in areas closest to the ground, such as basements and lower levels (Ruano-Ravina et al., 2014). There is a linear correlation between radon concentration levels and cancer risk: the higher the levels, the greater the likelihood of developing lung cancer (EPA, 2002). Therefore, it is crucial to encourage behaviours that protect against radon gas within society.

From a historical perspective, the study of radon risk exposure began through the coordinated action of the International Commission on Radiological Protection (ICRP) in the late 1950s, especially among uranium mining communities, and has evolved since then (Lopes, 2001). From 1928 to 1934, the ICRP issued recommendations related to exposure to radon gas in the whole body and extremities (Lopes, 2001). Both the World Health Organization and the European Union emphasize the importance of communication about radon and its risks to public health.

In summary, risk communication is a crucial multidisciplinary field for informing and guiding public decisions vis à vis health and environmental risks. Risk perception, trust in the source of information, and message complexity are key factors in the risk communication process. The evolution of communication in the digital age and social media present additional opportunities and challenges in this field.

3. Methods

Assuming the importance of communication in risk prevention and the relevance of making visible sources with expert knowledge, our primary objective is to analyse the role of the scientific community in Spain in the face of a persistent and constant risk such as radon gas. The impartiality and objectivity of experts and the scientific community, who are free from potential conflicts of interest, are key factors in raising public awareness of risk. This source of information is perceived as the most credible, and therefore its role in promoting self-protective behaviours in society is essential (Glynis, 2000). To characterize this role, we've established a series of secondary objectives:

1. Analyse how the Spanish scientific community perceives the communication of the risks posed by radon gas;

2. Detect the main challenges that the Spanish scientific community faces when informing the population about the risks posed by radon;

3. Identify improvements in the communication of radon-associated risks as a public health problem.

To achieve these goals, we've based our research on a qualitative methodological design supported by the triangulation of two research techniques: on the one hand, literature review, key to substantiating the study and to the discussion section; on the other, the semi-structured, in-depth interview, which includes a quantitative question, with experts from Spain's main scientific research centres[1]. The script for these semi-structured interviews is divided into five main sections to organise the results. The first two sections focus on identifying aspects of the research centre or interviewee and approaching the subject of study. The third section focuses on their perception of, and role in, communicating about radon. The fourth and fifth sections focus on areas for improvement, possible solutions and responsibilities.

3.1. Identifying research centres

This study immediately confronted a significant limitation: the absence of an organization, body, database, or tool that compiles all the research centres that have worked, directly or indirectly, on aspects related to radon in Spain. Therefore, this study began with an initial exploratory effort aimed at identifying which actors in the

1 Interested parties can request the script for the semi-structured interviews from the authors.

Spanish scientific community are connected to radon gas research. The following steps were taken:

1. Design of the database from an exploratory study: an ad hoc tool was developed to find the research centres registered across the territory that may deal with radon as a subject of study. The selected areas were Agriculture, Fundamental and Systems Biology (BFS), Plant and Animal Biology, Ecology (BVAE), Biomedicine (BMED), Food Science and Technology (TA), Earth Sciences (CT), Clinical and Epidemiological Medicine (MCLI), Chemistry (QMC), and Chemical Technology (TQ). This instrument was created using data provided by the Ministry of Science, Innovation, and Universities. As a result of this exploration, the initial database consisted of 544 research centres potentially dealing with radon.

2. Refinement of the database: Once the tool was developed, we contacted the research centres and asked them to complete a brief questionnaire about their lines of research so as to confirm whether radon or environmental radioactivity were among them.

3. Snowball strategy: Through our communication with the initial research centres, we obtained other previously unidentified contacts, thereby expanding the sample as much as possible.

4. Final Database: Finally, we arrived at a total of 26 research centres that work or have worked with radon as an object of study. Table 1 lists their names and their institutional affiliations.

3.2. In-depth interviews of experts

Using our ad hoc database, we emailed directors, representatives, or lead scientists affiliated with the identified research centres to conduct in-depth, semi-structured interviews, a type of interview known for its ability to "gain information through a professional conversation with one or several individuals for an analytical study" (Ruiz Olabuénaga, 2007, p. 165). As in our case, such interviews typically involve individuals with expert knowledge in the field (Van Audenhove and Donders, 2019). Refraining from closed-ended questions allows for greater flexibility and for adapting the script to the interviewee's responses (Treadwell, 2019).

Ultimately, a total of 13 online interviews were conducted with radon experts from various research centres across Spain (Table 2). All the interviewees are university professors or researchers in the fields of physics, medicine, or geology with extensive experience in radon R&D research projects. They were conducted between June

Table 1. Research centres with current or past focus on radon

Name	Institution
Laboratorio de Radon de Galicia	Universidade de Santiago de Compostela
Unitat de Radioquímica Ambiental i Sanitària (URAIS)	Universitat Rovira i Virgili
Institut de Tècniques Energètiques (INTE)	UPC Universitat Politècnica de Catalunya
Grup de Recerca en Radiacions Ionitzans (GRRI)	Universitat Autònoma de Barcelona
Laboratorio de Radiactividad Ambiental (LRA)	Universitat Politècnica de València
Laboratorio de Radioactividad Ambiental (UMA)	Universidad de Málaga
Laboratorio de Radiactividad Ambiental (LAUREX)	Universidad de Extremadura
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT)	Ministerio de Ciencia e Innovación
Grupo de Petrología Aplicada	Universidad de Alicante
Centro Nacional de Sanidad Ambiental (CNSA)	Instituto de Salud Carlos III
Ingeniaritza Energetikoa Saila	Euskal Herriko Unibertsitatea
Laboratorio de Física de Radiaciones y Medioambiente (FRYMA)	Universidad de Huelva
Grupo de Investigación en Interacción Radiación-Materia (GIRMA)	Universidad de Las Palmas de Gran Canaria
Grupo Experimental de Radiaciones Nucleares (GERN)	Universidad de Extremadura
El Laboratori de Radiologia Ambiental (LRA)	Universitat de Barcelona
Laboratorio de Análise de Radiacións (LAR-USC)	Universidade de Santiago de Compostela
Laboratorio de Física Médica y Radioactividad Ambiental (FIMERALL)	Universidad de La Laguna
Laboratorio de Investigación en Baja Radioactividad (LIBRA)	Universidad de Valladolid
Laboratorio de Radiactividad Ambiental (LaRUC)	Universidad de Cantabria
La Unidad de Salud Medioambiental Pediátrica	Hospital Universitari i Politècnic La Fe
Grupo de Radioactividade	Universidade da Coruña
Laboratorio de Técnicas Instrumentales e Instalación Radiactiva (LTI)	Universidad de León
Laboratori de Radioactivitat Ambiental (LARAM)	Universitat de València
Servicio de Radioprotección – Unidad de medidas de radón	Instituto de Salud Carlos III
Instituto de Ciencias de la Construcción Eduardo Torroja (IETcc)	Consejo Superior de Investigaciones Científicas
Instituto Geológico y Minero de España	Consejo Superior de Investigaciones Científicas

Source: developed by authors.

Table 2. Interviewees' affiliations

Interviewee	Date	Research centre
P1	May, 2022	Laboratorio de Radiactividad Ambiental (LaRUC)
P2	September, 2022	Laboratorio de Radon de Galicia
P3	April, 2022	Unitat de Radioquímica Ambiental i Sanitària (URAIS)
P4	May, 2022	Grup de Recerca en Radiacions Ionitzans (GRRI)
P5	April, 2022	Laboratorio de Física de Radiaciones y Medioambiente (FRYMA)
P6	April, 2022	Grupo de Petrología Aplicada
P7	May, 2022	Grupo de Radioactividade
P8	May, 2022	Centro Nacional de Sanidad Ambiental (CNSA)
P9	June, 2022	Ingeniaritza Energetikoa Saila
P10	January, 2023	Laboratorio de Análise de Radiacións (LAR-USC)
P11	May, 2022	Laboratori de Radioactivitat Ambiental (LARAM)
P12	May, 2022	Laboratorio de Física Médica y Radioactividad Ambiental (FIMERALL)
P13	March, 2023	Instituto de Ciencias de la Construcción Eduardo Torroja (IETcc)

Source: developed by authors.

2022 and March 2023 on Microsoft Teams. Each interview was transcribed and then processed and analysed to organize the data obtained based on themes, stances, or ideas, thus establishing connections and identifying patterns in the qualitative information gathered (Sabariego-Puig et al., 2014).

4. Results

4.1. Communicating the risk of radon gas

This research also provides a database of the main centres and research units of reference in the study of radon gas. Many of these centres have been interviewed. Having analysed the data, we find a consensus among the interviewees regarding the challenges they face in communicating information about radon, leading to the conclusion that "the public is not well-informed" (P1). We've identified at least two main factors contributing to this situation.

Firstly, the dissemination of scientific information about radon is complex and filled with technical jargon, which prevents the lay public from understanding and assimilating it. As one interviewee stated, "This information usually doesn't reach the general public, and the general lack of knowledge about the topic prevents further exploration" (P13). In fact, some scientists pointed out that low levels of formal education and lack of prior knowledge about radon leads to "misunderstandings about the conveyed information" (P11).

In this regard, experts highlighted the challenge of bridging the gap between the scientific realm and the general public. To this end, some emphasized the need for greater communication skills, aiming to "reach people with the certainty that I am correctly reaching the different groups I can address (young children, the elderly...)" (P7).

Generally, the interviewees are aware that their resources and training influence their communication efforts, which results in the information they convey being limited to a small number of people: "It's true that if you focus on audiences that don't follow radon-related topics, they are audiences that don't receive much information" (P6).

However, at the same time, the interviews also reveal that some scientists view the dissemination of information about the risks posed by radon gas as inadequate: "There needs to be greater dissemination; radon communication actions are few and far between. I haven't seen any information, either locally or nationally, about radon that could reach the general population" (P3). As such, some scientists call for awareness and communication campaigns so that the citizenry and "even some involved sectors" (P6) are informed about the gas's effects on public health and the existing preventive measures.

Secondly, interviewees also consider the general lack of public awareness about the gas's effects on public health and the need for preventive or mitigation measures hampers the relevant risk communication. They attribute this situation to the lack of media coverage and the scarcity of communication actions that can bring this topic closer to the general public. Various factors contribute to this, such as the lack of awareness itself, which can extend to the media, the fear of alarming the population by spreading news about radon, or prioritizing the communication of other risks of greater magnitude:

There is increasing awareness and media coverage, but I think it remains inadequate. This inadequacy could be due to the fact that it's not as dramatic compared, perhaps, to traffic accidents, which are more impactful. The problem with the effects of radon is that they are long-term. Additionally, the effects of radon are also masked by the effects of smoking. There's no doubt that when someone suffers from lung cancer,

everyone immediately thinks of tobacco. It doesn't occur to anyone that, in their home or region, there might be radon concentration levels above the limits. Smoking is overshadowing radon (P12).

Nevertheless, experts also emphasize that information about radon gas must be disseminated with caution, responsibility, and sensitivity, given that it represents a radiological risk that is difficult for many people to understand and is a threat to public health: "not just radon but the word radioactivity creates concern in the population" (P3). It's about informing the population "very carefully" (P2) about its effects and preventive measures, in order not to cause unnecessary or disproportionate alarm: "We must offer well-substantiated information while trying to avoid alarmism that can scare people. Dissemination should have a more positive approach" (P8).

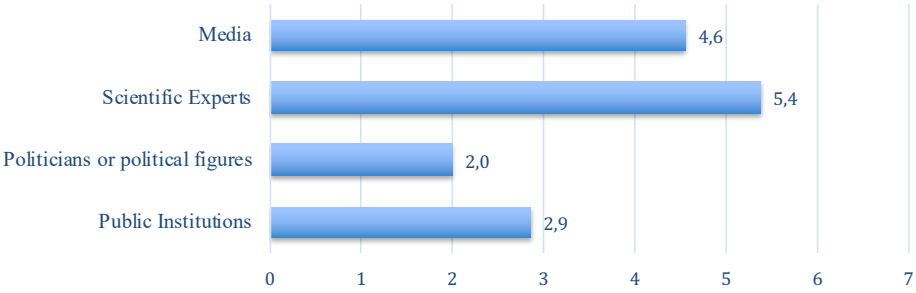
However, some interviewees highlight the media's occasional sensationalism or alarmism in conveying information about the effects of radon gas on public health. According to some specialists, this can originate from relying on unreliable sources or unverified information:

The general population is largely unaware. In some areas, they might be more informed in certain cases, but it's likely that there is a significant bias. Because instead of informing people, in many cases, there has been alarmism. There should be an effort to gather information from more reliable sources and ensure that this information is not biased by any kind of interest (P7).

In spite of the foregoing, the interviewees acknowledged that the information about radon disseminated by the media is more accurate than that disseminated by political figures or public bodies, though they also called for "greater coverage" (P4/GRR) of the issue. Finally, according to the experts we interviewed, communication from the scientific community is perceived as the most accurate and reliable.

Figure 1 shows the interviewees' satisfaction with the communication about the dangers of radon for public health and the prevention mechanisms carried out to date by different institutions, that is, the media, political figures, public institutions, and the scientific community itself. The interviewees expressed that they are most satisfied with the communication by other experts. However, the score is only 5.4 out of 7, indicating that despite their commitment to disseminating information about radon, there is still room for improvement. The media ranked second (4.6), revealing a medium level of satisfaction with how radon gas is covered in the news. Public institutions (2.9) and political figures (2.0) received lower scores. The interviewed Spanish scientists gave them a failing grade and demanded greater involvement in communication and awareness about radon's health risks.

Figure 1. Interviewees' satisfaction with radon communication by major institutions and figures (0 lowest; 7 highest)



Source: developed by authors.

4.2. Improving risk communication

In light of the current situation, the interviewed scientists suggested certain key considerations and measures that should be taken into account: increased dissemination of information about the effects of radon gas on health; a well-defined and effective communication strategy to raise awareness and educate the public about the risk of the gas in specific geographic areas in the country; avoiding generating undue alarm; and leveraging the advantages of digital communication to reach as many people as possible.

First, there is unanimity on the importance of a well-informed public opinion regarding the dangers of radon for public health and the corresponding prevention and mitigation measures, as only then can citizens make informed decisions:

> "People need to know that radon is a gas that is everywhere and, therefore, when we live in a closed environment, we need to be informed about radon levels and what measures we should take" (P12).

> "It is very important for people to be aware of this. It is a type 1 carcinogen as declared by the World Health Organization and is part of the natural risk we are exposed to. [This awareness] is a right of the population" (P4).

However, they held that this communication should be prioritized and fundamentally focused on regions where radon gas naturally exists at higher concentrations and consequently poses a greater risk: "It's very important that the general public

be well-informed, but it also depends on the area. There are places where it's more important than others" (P11). In terms of communication, the interviewees favour a strategy based on consistency and firmness over time with the aim of maintaining public attention and avoiding sporadic communication actions that fail to resonate with people. They highlighted the need for more segmented communication, targeted at smaller groups of people to create an environment for information to be conveyed correctly and to have greater efficacy and impact. The researchers proposed local initiatives focused on areas where radon gas is present at higher concentrations, e.g., "by communicating at town halls or neighbourhood assemblies" (P13) as these are considered "much more personal and lead to greater interpersonal sharing of information" (P1).

Third, there is emphasis on the need to avoid bias, alarmism, and sensationalism when communicating information. Hence, there is a demand for "very informative and clear information" (P6) to reduce bias and undue or disproportionate alarm about the real risk posed by radon.

Finally, the interviewees highlighted the fundamental role of digital communication, especially social media, in reaching broader audiences: "If knowledge and perception about radon today is somewhat low, before the arrival of digital communication and social media it was non-existent" (P12). However, the interviewees stressed that the advantages of digital tools and platforms should not be exploited to "create an abundance of information without monitoring and rigor" (P1), as the result is an infodemic that undermines any effort to educate and keep the population informed about a public health risk.

Nevertheless, the interviewees opined that social media's potential for communicating about radon is still largely untapped: "There is a problem in that sense, because there is a lot of information, but it doesn't reach people. An initial input is needed to awaken interest in people and redirect them to that information" (P5).

5. Discussion and conclusions

In this study, we have analysed how the Spanish scientific community views its communication to society that radon gas is a public health problem. The results indicate that, critically, the researchers themselves feel that they face certain difficulties in disseminating the information they handle and generate through their research. All these difficulties have a common denominator: the public's general lack of knowledge about any aspect of radon, be it origin, concentration levels, effects, prevention, etc.

In this context, the need to overcome the barrier that separates the layman from the scientist emerges as one of the main challenges. It is urgent that researchers acquire communication skills so as to turn complex, technical information into something digestible for the general public. The frequent and abundant use of technical terms adds to another reality suggested by previous studies: that generally, information related to science, by itself, does not usually interest the public (Denia, 2020). Despite scientific experts being perceived as reliable sources of information (Breakwell, 2000), the Spanish scientific community recognizes the limited reach of their messages, at least in terms of communicating the effects of radon gas on public health.

Thus, the foregoing indicates that risk communication requires an interdisciplinary approach (Bouder et al., 2012) to involve all stakeholders in truly effective communication about a given public health problem. We have found that the scientific community in Spain identifies two potential allies and partners in this task: the news media and the public administration.

First, the media, as intermediaries between the news and the public, are considered key players in keeping citizens informed about the health risks of radon, but also about the various prevention and mitigation measures. Journalism, understood as a public service, must help to keep society informed and educated so that people can make informed decisions. However, news coverage of radon is still inadequate in the eyes of Spanish scientists. This perception is in contrast with the findings of recent studies that demonstrate that information about radon gas published in digital media has gradually increased since the turn of the century, at least in specific regions of Spain (Negreira-Rey and Vázquez-Herrero, 2022).

Second, the public administration, as a stakeholder organization, is suggested as another key actor for generating quality information that improves current communication and contributes to raising awareness about the risk of radon to public health. As public service providers, such government bodies are called upon to play an active role in risk management and in what is known as instructional communication, key in public risk communication, so that people understand, perceive, and assess risks to protect themselves (Johansson et al., 2021). Some academic studies have shown that public institutions, along with private ones, are increasingly aware of their responsibility in managing risk and generating messages intended to persuade the receiver public (Leiss, 1996). Nevertheless, the Spanish scientific community highlights a widespread lack of public awareness, training, and general communication actions regarding radon gas. They demand a greater commitment vis à vis radon so as to raise awareness among the population about the gas's health effects so that it

can make informed decisions. The scientists we interviewed stressed the importance of neighbourhood-level or municipal localism when designing campaigns and risk communication actions, with segmentation based on the degree of radon concentrations in the area.

On the other hand, for risk communication to be effective, it is essential to understand the perceptions and attitudes towards the risk itself (Rohrmann, 2008). The Spanish scientific community decries a general lack of awareness about the existence of radon gas and its effects on health, which reflects the lack of awareness and information campaigns aimed at citizens, but also by what the interviewees consider to be insufficient media coverage. As some studies have demonstrated, this lack of information conditions the perception of the severity of the risk (Griffin et al., 2004), which in the case of radon gas has been associated with limited knowledge about its seriousness (Khan & Chreim, 2019).

With a view to more effective risk communication about radon gas, the scientific community points to digital media and social networks as potential drivers of change. Digitalization has allowed messages to reach a greater number of people; in the field of health, it has been shown that more and more people turn to websites, mobile apps, and other digital platforms for information (Masilamani et al., 2020). However, the information needs to be relevant and useful so that the message receivers related it to their concerns or interests. Moreover, scientists and journalists need to communicate carefully so as not to cause undue alarm or sow confusion among the population. In this sense, experts emphasize the importance of informing the public about the effects of radon gas on health and the relevant prevention and mitigation measures. As such, there are two underlying purposes: to provide citizens with the necessary tools to protect themselves and make informed decisions, but also to avoid generating a disproportionate sense of alarm about the risk posed by radon.

In summary, this study highlights the need to improve communication about the risk of radon gas in Spain. Scientists recognize the challenges they face in disseminating technical, complex, and distressing information to a population poorly informed about radon and its effects. Bridging this gap between science and society has become an urgent task. The media and the public administration stand out as essential allies in this mission, although there is still work to be done to increase media coverage and public awareness. Localized segmentation is discussed as an effective strategy to reach specific populations. In addition, digitalization and social media offer significant opportunities to disseminate information, as long as the communication thereof balances utility and responsibility. Ultimately, the goal is to empower citizens to make informed decisions and protect themselves without creating an undue sense of alarm. In short, for there to be effective risk communication about radon gas, all stakeholders will need to work together.

Further research on risk communication is needed, with special focus on digital platforms and the media. At the same time, it is also important to compare this evidence with new research incorporating the insights of risk communication experts. This will enable a more in-depth exploration of the issue. Likewise, future research should evaluate the relative success or failure of the scientific community in raising awareness and communicating effectively about radon gas in other countries where it is considered a public health issue. Our study has several limitations to be considered going forward. First, the lack of an official nationwide database containing the total number of groups, institutions, or research centres that study radon gas. This may mean that this study has not included certain actors. Limiting the sample to exclude other types of actors, such as politicians, the media, and other official parties, also constrains the scope of these results. Second, our results refer specifically to Spain. As such, it may not be appropriate to extrapolate our findings to other contexts.

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