RadoNorm
Managing risks from radon and NORM

Deliverable 6.1: Collection of existing methods, databases, scales, protocols and other tools – state of the art

Work Package 6

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Executive Summary of the RadoNorm project

EU member states, associated countries and the European Commission are implementing the European Basic Safety Standards Directive for radiation protection. The EU-funded RadoNorm project focuses on all radiation risk management cycle levels for radon exposure, as well as situations of exposure to naturally occurring radioactive materials (NORM). The project intends to reduce scientific, technical and societal concerns by introducing research and technical developments, integrating education and training (E&T) and disseminating the results of the project through targeted actions to the public, stakeholders and related institutions. RadoNorm directs research and development on all levels of the management cycle, combine biomedical and ecological research with mitigation development and social science research and bring together researchers from national radiation protection entities, universities and SMEs.

Executive summary of the deliverable

One of the objectives of the RadoNorm project is to improve methodological qualities of the research related to investigations of societal aspects of radon and NORM exposure situations. This document, the methodological state-of-the art, provides an overview of the methods that have been applied so far for investigating societal aspects of radon and NORM exposure situations as reported in scientific articles. This is the first attempt to perform a systematic review of the methodological approaches that have been used in social and human studies that aimed at understanding the socio-psychological situation of affected populations and stakeholders.

In order to gain an understanding of the state-of-the art in social and human research in the field of radon and NORM we performed a systematic review of literature in the following databases: Web of Science™, Scopus®, Medline and Sociological abstracts. A set of keywords was used to identify the relevant articles. All searches were performed in a period from 23.11.2020 to 01.12.2020. A total of 142 articles were included in the review, 123 of those investigated societal aspects in the context of radon and only 15 in the context of NORM. The remaining four articles covered both radon and NORM. In the majority of the articles (N=95) radon or NORM were the main focus of the investigation and in 47 instances, radon and NORM were just a part of a broader study.

Results of the systematic review demonstrate that there is a gap in research on societal aspects of radon and NORM exposure situations. This gap is especially evident for NORM as 9 out of 10 articles in this review investigated radon. Studies were primarily conducted on the local or regional level. Only in one article a survey was carried out in two countries. NORM was generally investigated on a geographically lower level than radon, reflecting the need to capture proximity to NORM industries. Furthermore, seven out of ten studies were conducted in the United States of America and only 28 studies were from European Union and the United Kingdom which points to the need of more studies in the European context. The majority of the articles focused on studying the general population. Traditional, long standing methods were used to collect data: in the quantitative studies, primarily surveys and experiments were used, while in the qualitative studies, interviews and focus groups were used most frequently. Moreover, this deliverable collected a broad range of variables and items that were used in radon and NORM studies and reports both the measurement scales and an assessment of their reliability and validity. It also gives a comprehensive overview of how ethical aspects have been addressed in the reviewed articles.

Several complementary reviews of methodological approaches that were performed within other tasks of WP6 are reported in appendix. These reviews highlight methodological challenges and opportunities in the particular topics related to radon and NORM exposure situations: communication interventions by

mass media and those related to radon on macro, meso and micro level, radon-related citizen science projects, marketing approaches for NORM in building materials and societal aspects of radon as treatment.

This deliverable can serve as a catalogue of methodological aspects in quantitative, qualitative and mixed method research related to radon and NORM exposure situations. Moreover, the results of this review will support development of methodological guidelines for investigating affected populations and stakeholders with special attention to different socio-political and cultural environments in the other tasks of the RadoNorm project. It will also contribute to development of the new and state-of-the-art methods and approaches to better address technical, health and societal aspects of radon and NORM exposure situations.

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Glossary

IAEA – International Atomic Energy Agency

ICRP – International Commission for Radiological Protection

NORM – Naturally Occurring Radioactive Material

SSH – Social Sciences and Humanities

SRA – Strategic Research Agenda

WHO – World Health Organisation

1. Introduction

The lack of research on societal aspects of radon and NORM exposure situations has been recognised as one of the most significant research gaps in radiation protection (Bouder et al., 2019; Impens et al., 2020; Perko et al. 2019; Turcanu et al., 2020). Social science and humanities (SSH) deal with human action in its social and cultural aspects and can contribute significantly and meaningfully to the management of exposure situations from radon and naturally occurring radioactive material (NORM). In particular, SSH research can help to improve understanding of the social, political, psychological, historical and economic factors that can influence perceptions, expectations and behaviours regarding radiological protection related to radon and NORM. Studies can be used to develop holistic approaches to governance of radon and NORM exposure situations; support Responsible Research and Innovation related to radon and NORM risk management and improve stakeholder engagement practices; develop effective risk and health communication and participatory radiological protection culture.

Research on social aspects of radon and NORM exposure situations is defined as a priority in the *Radiation protection research roadmap (Impens et al., 2020)*. Moreover, the updated *Strategic research agenda for social sciences and humanities research relating to ionising radiation* defines gaps related to societal research for radon and NORM exposure situations (Turcanu et al., 2020).

Although in radiation protection, a significant progress has been made on the inclusion of social sciences and humanities insight (Perko et al., 2019), however, "*work remains to improve further integration between the technical content and the societal context within which radiation protection operates. (…) Therefore, research and innovation in radiation protection needs to be better aligned with the values, needs and expectations of society in order that scientific research can inform decision making more effectively and for innovations to be responsive to, and acceptable by, societal need. Without effective means for radiation protection research to reach societal actors, (stakeholders, policy makers, publics) radiation protection knowledge and innovations will fail to generate societal benefits*." (Impens et al., 2020, pp. 31-32).

It is important to stress, that social science refers to such branches of knowledge as sociology, political science, communication studies, economics, psychology or cultural anthropology, whereas humanities cover in particular philosophy, ethics, law and history. These disciplines have their own research methods, whether qualitative, (e.g. in depth interviews, focus groups, observations etc.), quantitative (e.g. surveys, cost-benefit calculations, etc.) or mixed (e.g. social multi-criteria analyses, social network analyses, etc.)(Turcanu et al., 2020).

What is radon?

Radon is a radioactive noble gas produced as part of the decay chain of uranium or thorium radionuclides. Radon concentrations in the environment depend on the concentrations of uranium and thorium in rocks and soils, hence vary according to the geological characteristics of the area. Being a gas, it can also build up in poorly ventilated areas, and can be inhaled, leading to increases in risk of lung cancer.

What is NORM?

Raw materials extracted from the earth usually contain low concentrations of natural radionuclides such as uranium and thorium. When these raw materials are used in industrial processes, by-products and residues with elevated concentrations may be formed, so called NORM (Naturally Occurring Radioactive Materials).

The importance of a standardized approach in investigations of societal aspects of radon and NORM exposure situations is recognised in the SSH SRA (Turcanu et al., 2020). It is stressed that social sciences and humanities research on ionising radiation in general, and on radon and NORM exposure situations in particular, should integrate insights from recent methodological evolutions in SSH. For instance:

- Examining the social, cultural, economic, (geo)political and historical context of research in various fields of ionising radiations research and applications, with particular focus on the rationales, possibilities, and limitations of research approaches and methods, as well as the social relevance of research hypotheses. (Research line 3: RRI).
- Developing methodologies and tools for the dynamic mapping of stakeholders' concerns, views and needs to identify R&D priorities in the development of ionising radiations uses and radiation radiological protection. (Research line 3: RRI)
- Methodological research supporting the development of valid and reliable measurement scales for different latent constructs, questionnaires and health surveillance protocols for development of communication and evaluation of communication outcomes. (Research line 5: Communication)
- Exploration of methods for the co-construction or radiological protection culture, relaying on the contribution from radiological protection experts together with the stakeholders themselves for the development of skills, knowledge and practical measures combining science, expertise and practical experience. (Research line 6: RP culture)
- Development of methods and tools for the qualitative and/or quantitative evaluation of the degree of radiological protection culture, at group and or individual level. (Research line 6: RP culture)

The RadoNorm project addresses these methodological gaps.

This document provides a state-of-the art overview of the methods that have been applied so far for investigating societal aspects or radon and NORM exposure situations as reported in scientific articles. This is the first attempt to perform a systematic review of the methodological approaches that have been used in social and human studies related to the broad field of NORM and specifically radon and aiming at understanding the socio-psychological situation of affected populations and stakeholders (e.g. the building industry, health professionals, local, national and regional authorities, politicians, the remediation industry, those responsible at institutions, schools and universities). From its conception, this methodological document is intended as a dynamic document to encourage researchers of societal aspects of radon and NORM exposure situations to use standardized methods for gathering and processing data, as well to develop, test, re-test and share new methods.

The results of this review will support development of methodological guidelines for investigating affected populations and stakeholders with special attention for different socio-political and cultural environments in the other tasks of the RadoNorm project. They will also contribute to the development of new and state-of-the-art methods and approaches to better address technical, health and societal aspects of radon and NORM exposure situations.

This deliverable is structured in the following way. First, we will provide a short overview of the different methods that are used in social science research, including some reflections on the aspects of reliability and validity, and ethical issues (Chapter 2). Chapter 3 will describe the methodological approach applied for this systematic review from literature search to data extraction and analysis. Chapter 4 will present the results of the review followed by a general discussion and conclusion in Chapter 5. In addition, in Appendix E we briefly present several complementary literature reviews that were performed in the context of other tasks within the WP6 of the RadoNorm project.

2. Theoretical background

In this report we assess the methodological state-of the art. We will, therefore, give a brief overview of the different methods that are applied for data collection in SSH research.

There are two broad categories of research methods in social sciences: quantitative and qualitative. In some cases, a combination of different methods can be used as well, which is referred to as mixed methods. In this chapter we will give a short overview of these categories and the different approaches that are used for data collection. We will also explain how reliability and validity assessments can be performed in quantitative and qualitative studies and present some of the ethical aspect to be considered in the research methodology.

The choice between the different types of research methods depends on the type of problem that is investigated. If the concept or phenomenon has hardly been studied before, then usually a qualitative approach is fitting. While a quantitative approach is used if the goal is to test or explain (aspects of) an already established theory. Mixed methods allow to first explore the variables and to then make interferences on a large scale. Researchers own preferences and training also influence this choice and so do the preferences of the audience to whom the research is mainly addressed (Creswell, 2009).

2.1 Quantitative methods

Quantitative research has the objective to examine the hypothesized relationship, derived from theory, between variables. By collecting numerical data which are analysed using statistical procedures, hypotheses are then accepted or refuted. The advantages of quantitative research are that alternative explanations can be controlled for and that findings can be generalized and replicated (Creswell, 2009)

There are four main techniques for quantitative research: survey research, experimental research, content analysis and secondary research.

In *survey research* data is systematically collected using a standardized procedure, from a sample of the population, with the intent to generalize the findings to the larger population. Most commonly, questionnaires or structured interviews are used to collect data, either cross-sectionally or longitudinally (Ponto, 2015).

Experimental research is used to investigate causal effects. There are three types: true (lab-) experiments, quasi-experiments and natural experiments. The difference is that only in true experiments an independent variable is manipulated by the researchers and random assignment of the participants to treatment conditions is required. In quasi-experiments the random assignment is not-possible and in natural experiments, the manipulation occurs outside of the control of the researcher (Toshkov, 2016).

For *content analysis*, data is collected from textual, visual or aural material such as articles, recordings or pictures. Content analysis can be carried out both quantitatively as well as quantitatively. The difference is that for quantitative analysis, the data is systematically categorized and coded in a numerical way, so that it can be analysed using statistical methods (Scheufele, 2008).

The last main technique, there is *secondary quantitative research*. Here, existing data is collected to answer a different question or to summarize or validate outcomes which were found by other researchers (Lewis-Beck, 2004).

Data analysis in quantitative studies

In quantitative analysis, data is collected and/or transformed into numerical data and statistically analysed. There are two main types of analysis: descriptive analysis and inferential analysis. The former is used to summarize variables and find patterns, the latter to investigate relationships between variables (correlation or causation).

The choice of analysis technique is determined by the research question, hypotheses, and the nature of the data (nominal, ordinal, interval, ratio, cardinal, categorical). Statistical knowledge and skills are a prerequisite for such analysis (Jung, 2019). Statistical analysis software such as SPSS and Stata, are often used to assist researchers with analysis of quantitative data.

2.1.1 Reliability and validity

In any quality assessment of the research one should consider the rigour of its measurement procedures. The two psychometric properties of the measurement scales that are commonly used to assess the accuracy of the measurement procedures are called reliability and validity (Bhattacherjee, 2012).

Reliability is used to assess whether the measure of the construct is consistent (i.e. will you get the same result if you measure the same construct under similar circumstances and/or multiple times) (Heale & Twycross, 2015). Reliability can be estimated in many ways:

- *Internal consistency* (homogeneity) – do all items on the scale measure one construct (e.g., Split half reliability; Kuder-Richardson; Cronbach's alpha)
- *Temporal stability* - are measurements of the same construct measured in the same way but at different points of time consistent (e.g., test-retest reliability, Intraclass Correlation Coefficient (ICC))
- *Parallel forms* – similar to temporal stability but a different form of original document is given to the participants (e.g. alternate forms reliability)
- *Agreement/Equivalence* – assesses level of agreement between two or more raters or observers (e.g., % agreement, phi, kappa, Kendall tau, Intraclass Correlation Coefficient (ICC))

Validity is "the extent to which a measure adequately represents the underlying construct that it is supposed to measure" (Bhattacherjee, 2012, p. 58) and can be assessed in both theoretical and empirical way.

- *Construct validity* - does scale measure the intended construct
- *Content validity* - does the scale cover all relevant parts of the construct
- *Criterion validity* – does scale relate to other instruments that measure the same construct
- *Convergent validity*: does scale relate to other scales it should correlate with
- *Predictive validity*: does scale predict outcome in future that it should predict
- *Factorial validity* – used to uncover internal structure of large sets of variables (exploratory factor analysis (EFA), confirmatory factor analysis (CFA))

2.2 Qualitative methods

Qualitative methodology refers to a broad range of methods that produce descriptive data (Taylor, Bogdan, & DeVault, 2015) and can provide a deeper understanding of the studied social phenomena (Gill, Stewart, Treasure, & Chadwick, 2008). Some of the most used data collection methods in qualitative research are interviews, focus groups, observations, and document analysis. Qualitative studies are however building on a very diverse range of data gathering methods, often combining or adapting some of the aforementioned techniques (e.g. ethnography, visual research, or mobile methods).

Interviews can be divided into three distinct types: structured, semi-structured and unstructured. Structured interviews are essentially open-ended questionnaires that are administered verbally. Semi-structured interviews contain some key questions, but are otherwise flexible and allow for elaboration

and discovery of new topics (Gill et al., 2008). Unstructured interviews do not use a set of questions and mimic natural conversation. This kind of interviews are often used in the narrative research.

Focus groups share many characteristics with semi-structured interviews. With this method one can collect data simultaneously from many participants. Focus groups are essentially group discussions on a given topic that are guided by a moderator (Gill et al., 2008). The key aspect of the focus groups is the interaction between participants (Morgan, 2010). This method can be used to gather information on collective views, to explore participants experiences and beliefs, to clarify or confirm data collected through other methods (Gill et al., 2008) for anticipatory research on emerging topics that are not very known (Macnaghten, 2017).

Observation is defined as "the systematic description of events, behaviours, and artefacts in the social setting chosen for study" (Marshall, 1989, p. 79). Observation is the primary method for gathering data in the ethnographic research as it allows the researcher to “describe existing situations using all five senses” (Kawulich, 2005). Scholars distinguish between participant and non-participant observation and this distinction depends on the role that researcher takes in the setting chosen for a study (i.e. does he take place in the activities together with the studies subjects or not).

Content analysis is a systematic procedure for reviewing or evaluating printed or electronic material (Bowen, 2009). The data typically produced in a document analysis contains quotations, excerpts, passages that are then categorized into themes and categories, often using content analysis (Labuschagne, 2003)

Data analysis in qualitative research

Qualitative data collection methods often result in unstructured text-based data (transcripts of interviews and group discussions, observation notes, diaries, excerpts from documents etc.). Analysis of such data is “a dynamic, intuitive and creative process of inductive reasoning, thinking and theorising” (Wong, 2008, p. 14). The process of such analysis involves coding and categorizing of the data in order to identify patterns, draw some meanings and build a logical chain of evidence (Patton, 2002; Wong, 2008). In the past decades several digital tools have been developed to assist researchers with analysis of the qualitative data (e.g. ATLAS.ti, NVivo) (Maher, Hadfield, Hutchings, & de Eyto, 2018).

2.2.1 Reliability and validity in qualitative methods

Different ontological and epistemological assumptions underpin different qualitative methods and therefore a single set of processes to examine rigour cannot be applied to all qualitative methods. Instead, each method must be considered on its own terms; for example, inter-rater agreement on themes might be appropriate for some descriptive thematic analyses but would not be appropriate for some interpretative analyses. In order to help researchers critically appraise qualitative methods, four main criteria are widely used to appraise the trustworthiness of qualitative research: credibility, dependability, confirmability and transferability (Guba, 1994).

Credibility: The research findings are plausible and trustworthy. There should be a coherence between theory, research question, data collection and analyses; the specific sampling strategy, degree and depth of data, analytical stages align with the specific qualitative framework. Respondent validation and triangulation of data, researcher and/or method can support credibility.

Dependability: the extent to which sufficient information is provided so that the research’s procedural steps could be replicated, albeit possibly reaching different conclusions. An audit trail of the method can enhance dependability.

Confirmability: There is a clear link or relationship between the data and the findings; in essence, the interpretations are justifiable on the basis of the detailed descriptions and the use of quotes. An audit trail of the analysis process can enhance dependability.

Transferability: Findings may be transferred to another setting, context or group. Rich descriptions of context can be provided.

In addition, qualitative studies should also include a consideration of *Reflexivity*, i.e., the relationship of researcher to data in terms of the researcher's conceptual bias, explicit and implicit assumptions, values and how these impact on decision making through all phases of the research.

Finally, triangulation is another widely recognised strategy to test validity of qualitative research. Triangulation is the use of multiple methods and data sources to develop and understanding of a phenomenon (Carter, Bryant-Lukosius, DiCenso, Blythe, & Neville, 2014). There are several types of triangulation:

- method triangulation – use of multiple methods of data collection about the same phenomenon
- investigator triangulation – involvement of several researchers as observers or analysts in the same study
- theory triangulation – use of different theories to analyse and interpret data
- data source triangulation – collecting data from different types of people (incl. communities, families etc.)

2.3 Mixed Methods

A mixed methods design is a scientifically rigorous research project, driven by the inductive or deductive theoretical drive, and comprised of a qualitative or quantitative core component with qualitative or quantitative supplementary component(s) (J. M. Morse & Niehaus, 2016). The exploratory nature of research, the complexities of the phenomena studied in social science and humanities, and the limitations within methods result in situations when a phenomenon cannot be described in its entirety using a single method (J. M. Morse & Niehaus, 2016; J.M. Morse, Wolfe, & Niehaus, 2006). In order to investigate a complexity of people's behaviour related to radon or respond to a question at the macro level, (e.g. National/Policy Level e.g. Basic Safety Standards BSS Directive of EU), meso level (e.g. community or organisational level, e.g., Local Authorities, Le SAMI Walloon), as well as the micro level (e.g. a homeowner or renter) researchers might need to apply quantitative and qualitative types of research methods in the same project. Mixed methods research can be applied at the primary empirical study level as well as at the synthesis level. In a primary level mixed methods study a researcher collects qualitative and quantitative data directly from the research participants, for example through interviews, observations, and questionnaires, and combines these diverse data in a single study and on the synthesis level where the data included in a research are findings extracted from several published qualitative, quantitative, and mixed primary level articles (Heyvaert, Maes, & Onghena, 2011).

J.M. Morse et al. (2006) identify eight types of mixed methods design (see Table 7). These types are defined based on the principal component (priority) and supplementary component of the study design. Types of the mixed method approaches where components have equal weight are also included.

2.4 Ethical aspects

As for any area of applied research ethics, the ethical requirements for approval of social science studies have evolved over the years. In medical ethics, the concept of harm to research participants changed from an evaluation of the physiological risk to participants to one that included potential harms from psychological impacts. In recent years this has expanded to encompass potential impacts on privacy, dignity and well-being. This means that any study involving the participation of human research subjects, requires that the researchers address a range of ethical principles in order to meet the requirements for ethical approval.

Guidelines for ethics in social science research stress the importance of respecting basic ethical principles[1] such as doing good, not doing harm and protecting the autonomy, wellbeing, safety and dignity of all research participants. Researchers should be as objective as possible and avoid ethnocentricity. Respect for informed consent will be central to any evaluation and ensures the subject's free and voluntary expression of his or her willingness to participate in a particular study. The criteria for gaining consent requires provision of adequate information. In order for subjects to be able to choose 'freely' to participate in research, they need sufficient information about the research to know what their participation involves. If confidentiality and/or anonymity have been promised, then the steps taken to ensure this should be outlined. Adequate time needs to be given to the research participant or (for minors) legally designated representative to consider the decision to participate. In most cases, informed consent should be supplemented by an information sheet that describes the aims, methods, duration and implications of the research, the nature of the participation and any benefits, risks or discomfort that might ensue[2].

It should be clear that participation is voluntary and that subjects have the right to withdraw their participation, samples or data at any time — without any consequences. In recent years, the requirements for information often include the organisation and funding of the research. There has also been an increased focus of detailing how the results of the research will be fed back to participants.

The increased focus on privacy and the way data from research involving humans is utilized is reflected in the General Data Protection Regulation (GDPR) that came into force in the EU in 2016, and has also been adopted in a number of other countries (e.g. Norway). More information on the implications of GDPR for RadoNorm can be found in the ethical deliverables and data management plan of the project (Zeleznik et al., 2020). In short, researchers need to inform participants about the way their data will be stored, shared and eventually destroyed. This means that the information supplied to participants needs to detail how incidental findings will be handled (if applicable) and must contain a reference of a contact person and information about what will happen to the results of the research.[2]

Finally, in addition to ensuring that studies are carried such that they meet ethical requirements for the way the research is carried (internal research ethics), many research committees also address the broader consequences of the research itself, such as its societal or environmental impacts. They may also assess potential conflicts of interests of researchers, the role of funding or research institutions, and the independence and objectivity of researchers.

Recognising the change in criteria for gaining research approval over the last decades, in section 4.2 we look in depth into how ethical considerations have been addressed in the reviewed articles. The objective is not to judge the ethical justification of the reported studies, but rather to illustrate the different aspects that need to be addressed in carrying out social science research on radon and NORM. This should in turn ensure that RadoNorm studies meet the highest ethical standards, as well as highlight areas that are likely to be of increased focus in subsequent studies.

In the next chapter we describe the methodological approach taken to perform the systematic review of the literature.

[1] Ethics in Social Sciences and Humanities: https://ec.europa.eu/info/sites/info/files/6._h2020_ethics-soc-science-humanities_en.pdf

[2] Ethics and Data Protection: https://ec.europa.eu/info/sites/info/files/5._h2020_ethics_and_data_protection_0.pdf; Data protection: https://ec.europa.eu/info/law/law-topic/data-protection_en; Research Ethics in Ethnography/Anthropology: https://ec.europa.eu/research/participants/data/ref/h2020/other/hi/ethics-guide-ethnog-anthrop_en.pdf

3. Methodological approach of the systematic review

In order to gain understanding of the state-of-the art in social and human research in the field of radon and NORM we performed a systematic review of literature. In this chapter we will describe the approach taken for searching various databases, criteria for inclusion of relevant articles and procedures for data extraction. We will conclude with acknowledgment of some limitations of this review.

3.1 Literature search

The search strings were developed with the help of a librarian at the Norwegian University of Life Sciences (NMBU) and were adapted to the various databases. The following databases were searched: Web of Science™, Scopus®, Medline and Sociological abstracts (SA). We used text word search for all databases except Medline, where we used both text words and index words. All searches were performed in a period from 23.11.2020 to 01.12.2020.

We performed a wide search of literature since societal aspects of radon and NORM exposures could have been addressed in articles from different research fields, not just social and human sciences. Since our literature review covers the topics of both radon and NORM, the literature search was performed systematically in several steps (See Table 1) and using several combinations of the keywords (See Table 2).

First, we searched for a combination of radon and NORM -related words together with a variety of keywords related to the methods used in social science (SEARCH1, SEARCH3). In order to find the NORM -related articles, we utilized keywords related to the different industries that cause contamination with the naturally occurring radionuclides and combined them with the word “radioactive” to select only the articles where the radioactivity was mentioned.

Secondly, a separate search was performed for a combination of radon and NORM keywords with methods like ‘survey’ and ‘experiment’. These methods are very common in natural sciences as well as in social sciences and would, therefore, produce a large number of irrelevant papers if used alone. In order to narrow down the search we combined these terms with additional search terms like “public”, “respondents”, “participants”, “parents” etc. to ensure that we capture studies from social and human research (SEARCH2, SEARCH4)

In addition, we performed a search in the SA database using only “radon” and NORM -related keywords (SEARCH5). We decided to not add any methodological keywords in this search because the SA database already contains only social science articles. Furthermore, it lacked detailed informative abstracts and good meta-data which complicates the search. Use of methodological keywords could have caused loss of relevant articles.

In order to reduce the number of irrelevant articles, we limited the search in all databases to title and abstract where it was possible.

Full search protocols for this literature review can be found in Appendix A.

Table 1 - Overview of the different searches performed within the literature review

Search	Combination of topics	Databases
SEARCH1	NORM AND Method1	Web of Science, Scopus, Medline
SEARCH2	NORM AND Method2 AND Human Subjects	Web of Science, Scopus, Medline
SEARCH3	Radon AND Method1	Web of Science, Scopus, Medline
SEARCH4	Radon AND Method2 AND Human Subjects	Web of Science, Scopus, Medline
SEARCH5	Radon OR NORM	Sociological abstracts

Table 2 - Overview of the keywords used for the different search combinations

Search topic	Keywords used*
Radon	radon
NORM	(radioactiv*) AND ((natural NEAR/1 (radiation OR "radioactive material")) OR tenorm OR residue OR remainder OR leftover OR waste OR oil OR gas OR water OR phosphate* OR fuel* OR geothermal OR building* OR "flying ash" OR mining OR mine OR "NORM industries" OR "building material*" OR "alum shale" OR (environment* NEAR/0 remediation))
Method1	(((field OR case OR comparative OR cohort OR archival) NEAR/2 stud*) OR ((network OR content OR sentiment OR meta OR framework OR media OR discourse OR morphological OR text* OR conversation OR narrative) NEAR/2 analysis) OR ((systematic OR meta) NEAR/0 review) OR ((mixed OR mental OR mixed OR delphi OR q OR economic) NEAR/2 method*) OR "delphi techniq*" OR "focus group*" OR "repertory grid" OR "analytic induction" OR "life history*" OR historiography OR "socio mapping" OR "feeling thermometer" OR "cybermethod*" OR "participatory action" OR bibliograph* OR questionnaire* OR "secondary data" OR "e-research" OR "memory work" OR interview* OR observation* OR ethnography OR phenomenolog* OR RCT OR "randomized controlled trial*" OR workshop OR "public opinion" OR panel* OR omnibus OR poll OR triangulation OR hermeneutic)
Method2	(survey* OR experiment*)
Human subjects	(public* OR citizen* OR participant* OR respondent* OR resident* OR person* OR stakeholder*)

* - Search strings are in the Web of Science format

All the search results were downloaded into Endnote 20 and then uploaded into the Rayyan - a digital tool developed for literature reviews (Ouzzani, Hammady, Fedorowicz, & Elmagarmid, 2016). Using the Rayyan tool, the duplicates were removed prior to the inclusion assessment.

3.2 Inclusion criteria for articles and inclusion process

The inclusion assessment was divided into two steps. Step 1 (or initial screening) was performed to remove completely irrelevant articles based on reading their title and abstract. Ample attention was given to the overall reliability of the coding. The articles were divided between three reviewers with an overlap, 22% of the papers were assessed by at least two reviewers and differences were evaluated and remediated by the three reviewers together.

According to the pre-defined inclusion criteria for Step 1, the article was included if it was:

- published in a peer-reviewed scientific journal (i.e. conference proceedings were excluded)
- written in English
- investigated the topic of radon/NORM
- investigated public or stakeholders' risk perception, views, opinions, motivations, attitudes and behaviour (even if it was just a part of the whole study)

The Step 1 assessment resulted in 240 articles being included as relevant. These articles were investigated in depth to identify which of them were suitable for further analysis.

At Step 2, at least two reviewers had to agree that article was irrelevant for it to be removed. Articles were excluded if they did not fulfil one of the following criteria:

- no full text of the article could be found
- type of the article was other than original research paper (i.e. reviews, book review, discussion papers etc. were excluded)
- the article was not relevant (e.g. it didn't measure any variables relevant for social and human studies or focused on the wrong topic, for example, nuclear waste)
- no methodological information was provided

The Step 2 assessment resulted in 142 articles were included as the core of the review (Figure 1).

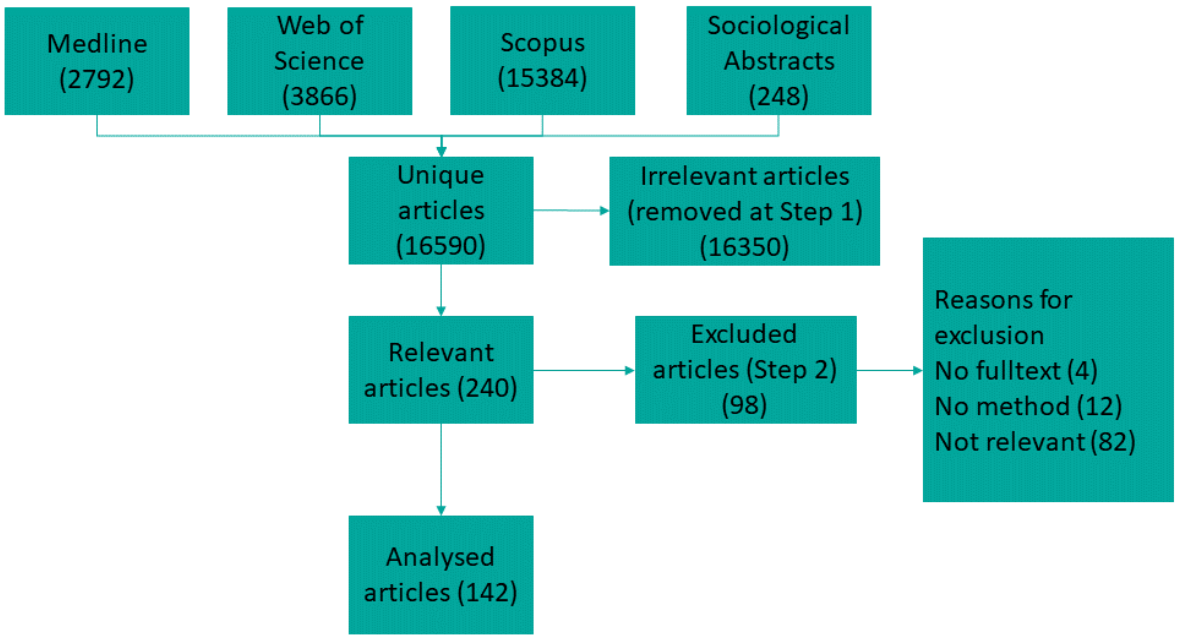

Figure 1 Search and analysis process and results

3.3 Data extraction

3.3.1 Development of the data extraction form

In order to facilitate data extraction, an online standardised data extraction form was created using Qualtrics. This form was developed based on the data extraction template of the Cochrane research institute (Higgins, 2020).

Following categories of information were extracted from each article: 1) citation information (publication year, author(s), title), 2) aim of the study, 3) population description, 4) setting, 5) sampling information (method, mode, size, response rate, representativeness), 6) study design (quantitative, qualitative, mixed methods), 7) dependent and independent variables (concepts and indicators), 8) methods (e.g. survey or interview), 9) analysis (type and software), 10) topic of the article (radon/NORM), 11) reliability, 12) validity, 13) data availability (e.g. database or questionnaire), 14) main conclusions and 15) ethical considerations (conflicts of interest, funding and privacy).

See Appendix C for full data extraction form.

3.3.2 Extraction procedure

In total 10 coders were involved in the data extraction. All coders were trained in data extraction by performing test extraction on the same articles, which was followed by a meeting where the disagreements were resolved. In addition, a glossary was developed explaining the different terms and data extraction variables to assist coders (see Appendix D).

The majority of the articles were coded independently by two coders. The conflicts in the extracted data between the coders were resolved by two master coders. Due to the varying quality in the description of the methodological approaches in the different included articles, data extraction was at times challenging. Since coders were asked to extract information as stated by the authors of the articles, some of the variables had to be re-coded by the master coders before the analysis. For example, the authors of the reviewed papers did not always use proper terminology for describing their sampling strategy (e.g. random sampling, snowball sampling, convenience sampling etc.). In such cases, coders extracted the relevant quotes from the articles instead of choosing one of the categories from the extraction form, and master coders made the final decision on the category to be applied. This decision was based on the extracted quotes or by reviewing the article in question.

3.4 Limitations of the review

There were following limitations to our review:

In order to ensure that relevant articles, that investigate the societal effects of radon and NORM exposure, would not be missed, a broad search was performed. This resulted in a high number of irrelevant articles that had to be manually screened.

Authors of the reviewed papers did not necessarily use the common terminology to describe methods and techniques, sometimes description was completely absent. This varied level of explanation influenced the data extraction quality since the reviewers had to categorize information independently, but it could also have impacted the search results.

Our review was limited to scientific papers published in peer-reviewed journals and, therefore, did not include grey literature or publication types such as conference papers. Since radon studies are often performed by governmental agencies responsible for public health or environmental/radiological protection some of the studies might only be published as internal reports and weren't included in this review.

We only included papers written in English. This could potentially explain the geographic overrepresentation of studies from English-speaking countries within the review. Especially studies on the local level could have been missed due to this language restriction.

We only included studies which contained a description of the methodology, this means that publications with the lowest methodological standards were excluded from our review.

In research there is a publication bias, meaning that in most cases only papers with statistically significant results are published, consequently these papers are more likely to be part of our review. At the moment, we were not able to do a genuine meta-analysis due to the heterogeneity of the aims and measures of the studies under review, so we cannot evaluate potential biases in that aspect. However, publication bias can be reduced by pre-registration of studies. The methods and analysis plan of these studies are evaluated in advance and the studies are published regardless of the statistical outcome.

4. Results of the systematic review

This chapter will describe the findings of the systematic literature review. First, we will present a general description of the whole sample of the reviewed articles, including topic of the articles, study designs and methods that were used, geographic setting of the studies, publication years and populations studied. We will then describe how some of the ethical aspects were handled in the reviewed papers (4.2). Finally, we will present further findings separately for quantitative (4.3), qualitative (4.4) and mixed methods (4.5).

4.1 General description of the reviewed articles

4.1.1 Topic of the reviewed articles

A total of 142 articles were included in our review (see Appendix B for full list), 87% of those (N=123) investigated societal aspects in the context of radon and only 10% (N=15) in the context of NORM. The remaining four articles covered both radon and NORM (see Figure 2). In the majority of the articles (67%, N=95) radon or NORM were the main focus of the investigation and in 47 instances (33%), radon and NORM were just a part of a broader study (see Figure 3).

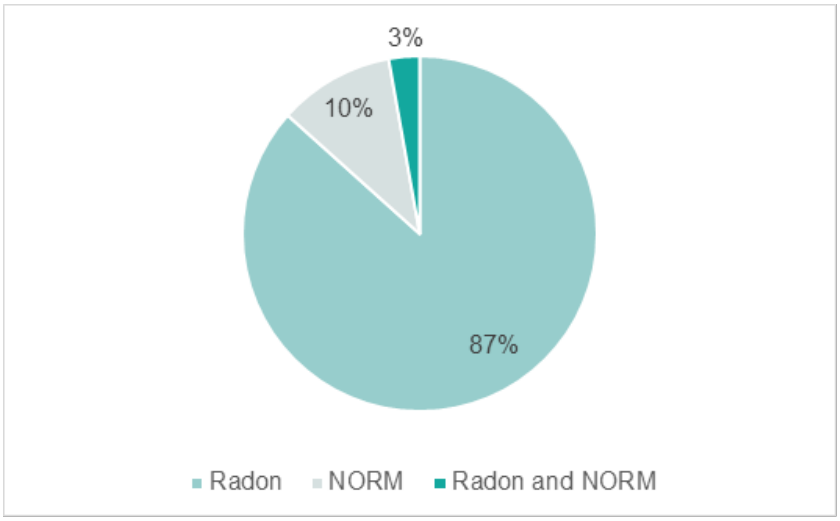

Figure 2 Proportions of radon and NORM articles in the sample

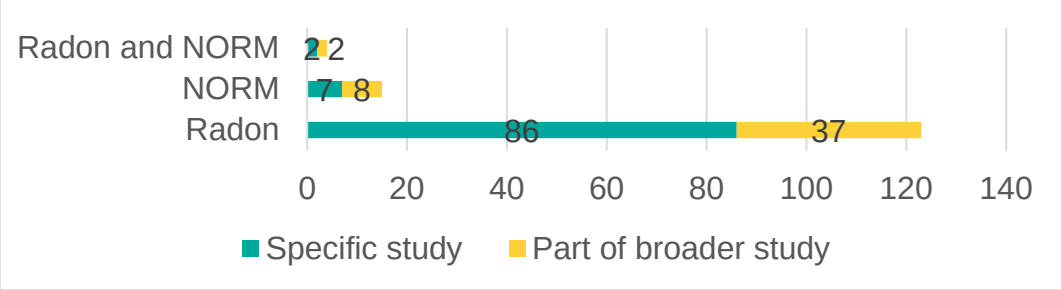

Figure 3 Focus of the reviewed articles (no. of articles)

In 87 articles the focus was specifically on radon, 40% of them investigated stakeholder's attention, awareness or knowledge about radon (e.g. Clifford, Hevey, & Menezes, 2012; Loffredo, Savino, Serra, Tafuri, & Quarto, 2020; Momin et al., 2018). In about one third of the articles, risk perceptions and attitudes were investigated (e.g. Hazar, Karbakhsh, Yunesian, Nedjat, & Naddafi, 2014; Khan, Krewski, Gomes, & Deonan, 2018). The other research stream focused on behaviours such as testing (37%), mitigation and remediation (20%) (e.g. Dowdall, Fenton, & Rafferty, 2016; Duckworth, Frank-Stromborg, Oleckno, Duffy, & Burns, 2002; Peterson & Howland, 1996; Weinstein, Lyon, Sandman, & Cuite, 1998). In a few articles, through educational activities, students were encouraged to investigate and measure radon independently (Groppi, 2018; Immé, Catalano, Mangano, & Morelli, 2013; Johansson, Nilsson, & Wachtmeister, 2007). While in others the synergic risks between radon and smoking were explored, by investigating people's perceptions and behaviours (e.g. Hampson, Andrews, Barckley, Lichtenstein, & Lee, 2000, 2006; Rinker, Hahn, & Rayens, 2013). Topics that were rather exceptionally studied include radon treatment (B. E. Erickson, 2007d), personality traits (Hampson et al., 2006), support for radon-related legislation (Martin et al., 2020) and emotions such as fear or apathy (Cothern, 1990; Dragojevic, Bell, & McGlone, 2014).

Articles that focused on NORM tended to investigate specific industry sectors, such as contamination sites (Delemos et al., 2009; Feldman & Hanahan, 1996), water management (Torres, Yadav, & Khan, 2017) or remediation processes (König, Drögemüller, Riebe, & Walther, 2014) than a more generalised approach. As such, these studies' settings were local, most of them being driven by the aim of authorities to minimise or prevent various forms of social pressure in the surrounding communities (Delemos et al., 2009; Feldman & Hanahan, 1996).

The broader studies (also called omnibus studies) that included radon or NORM related questions, collected data on a number of topic like: (1) knowledge and perceptions about a variety of risks, (2) knowledge of radioactivity (man-made and natural), (3) health-related behaviours, (4) smoking-radon lung cancer synergy and (5) environmental consciousness. NORM was mentioned as a part of the studies related to the energy sector.

4.1.2 Study design and methods

The majority of the reviewed articles had a quantitative design (108). This is followed by qualitative design (19) and articles using mixed methods (15) (Figure 4).

The data was primarily gathered through surveys (N= 123) and experiments (N= 17), this is followed by interviews (N = 14) and focus groups (N = 12) (Figure 5). The differences in quantitative and qualitative methods for data collection reflect the differences in study design (quantitative/qualitative) of the reviewed articles.

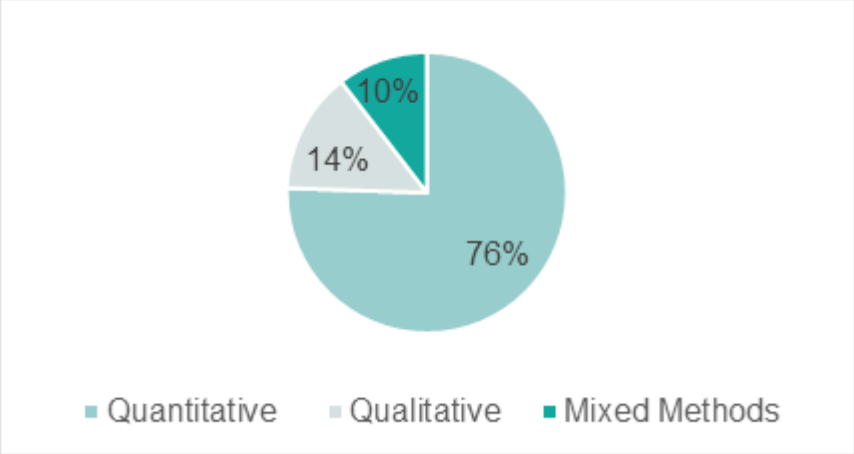

Figure 4 Study designs used in the reviewed papers

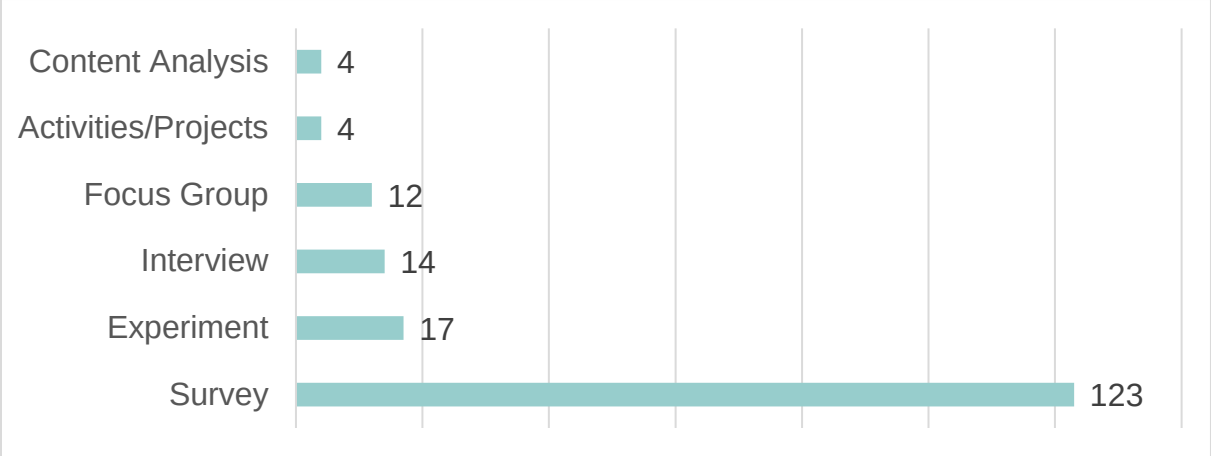

Figure 5 Main research methods used for data collection in the reviewed articles (no. of articles)

4.1.3 Geographic setting of the reported studies

The studies in the reviewed articles were conducted in 17 countries. Studies from the USA, UK, Canada and Australia made up 80% of the sample: USA (N= 97), UK (N= 10), Canada (N= 5) and Australia (N=1). The second largest group covers 18 papers, all conducted within a member country of the European Union. The remaining 11 are from Pakistan, Turkey, Iran, Korea and Switzerland. (Figure 6).

Only 23 articles were conducted nationwide and only one conducted an international study of two countries: Belgium and Slovenia. All the remaining articles were conducted primarily on the local (N= 61) and regional (N= 57) level.

NORM studies were mainly conducted on the local and regional level in the proximity of the NORM industries.

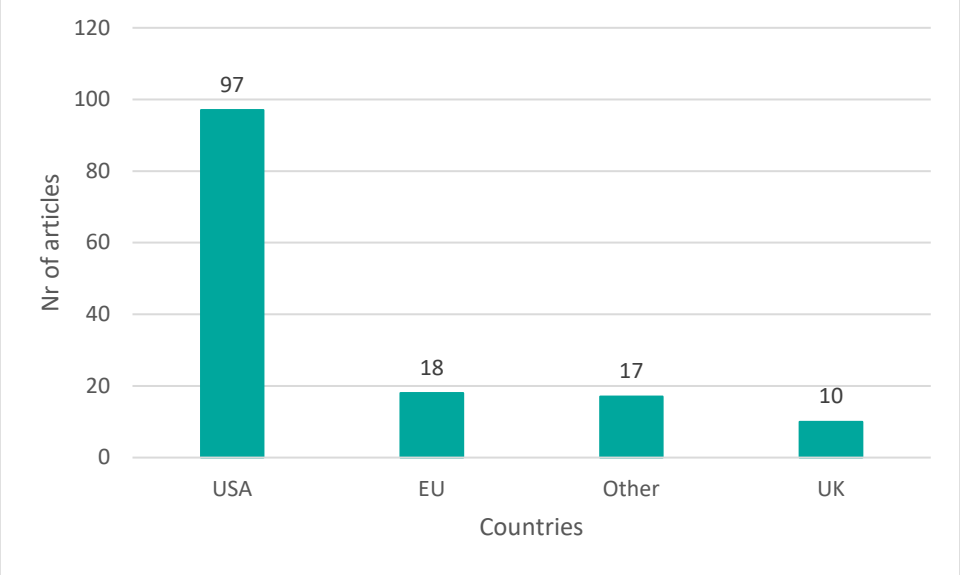

Figure 6 Overview of the countries radon and NORM studies were conducted in (no. of articles)

(Other: Australia, Canada, Korea, Pakistan, Switzerland, Turkey. UK is separated from EU as the country with most studies)

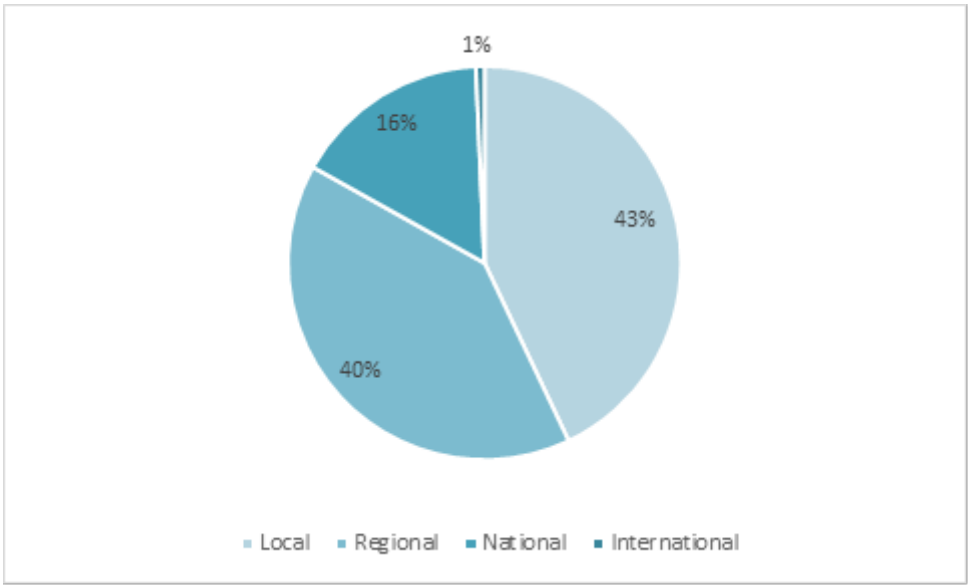

Figure 7 Geographic setting of the studies reported in the reviewed articles

To summarise this sub-chapter, Figure 8 presents an overview of all the reviewed papers with regard to the topic of the investigation, study design applied and geographic setting.

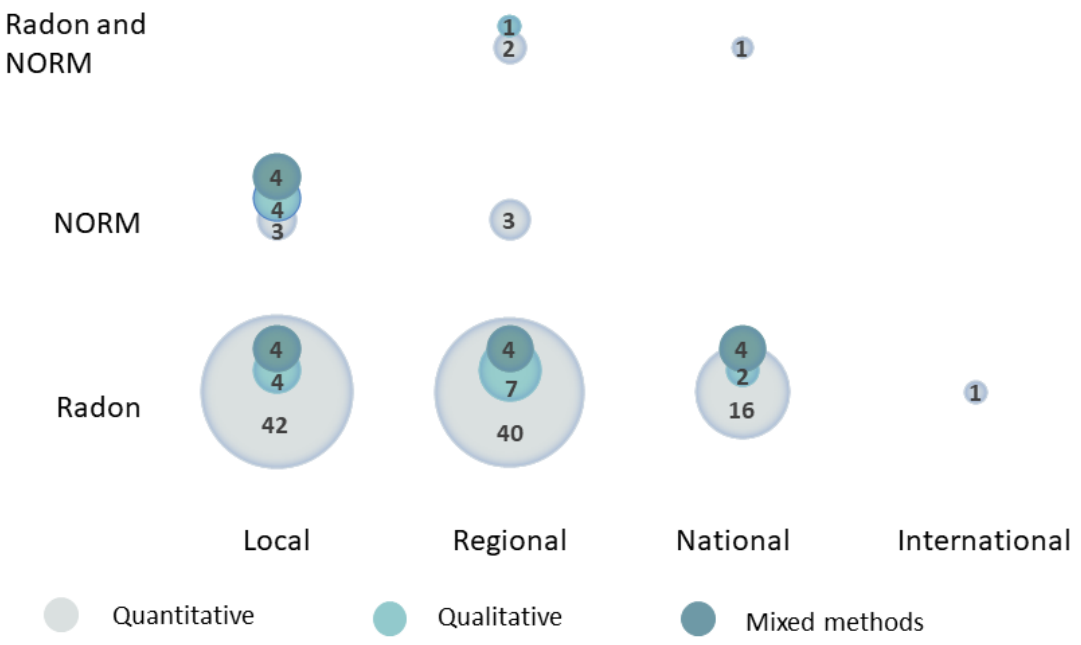

Figure 8 Overview of all the reviewed papers with regard to the topic of the investigation, study design applied and geographic setting

4.1.4 Publication year

All the articles included in this review were published in the time interval from 1987 to 2020 (see Figure 9). As previously discussed, the number of articles about radon is consistently higher than those about NORM throughout the years. A slight increase of publications can be observed in more recent years, which could be linked to publication of Council Directive 2013/59/EURATOM that introduced legally binding requirements on the protection from exposure to natural radiation sources and, in particular, to radon (EU, 2014)(2013). Otherwise, there is no clear trend and the overall number of articles concerning societal aspects remains low.

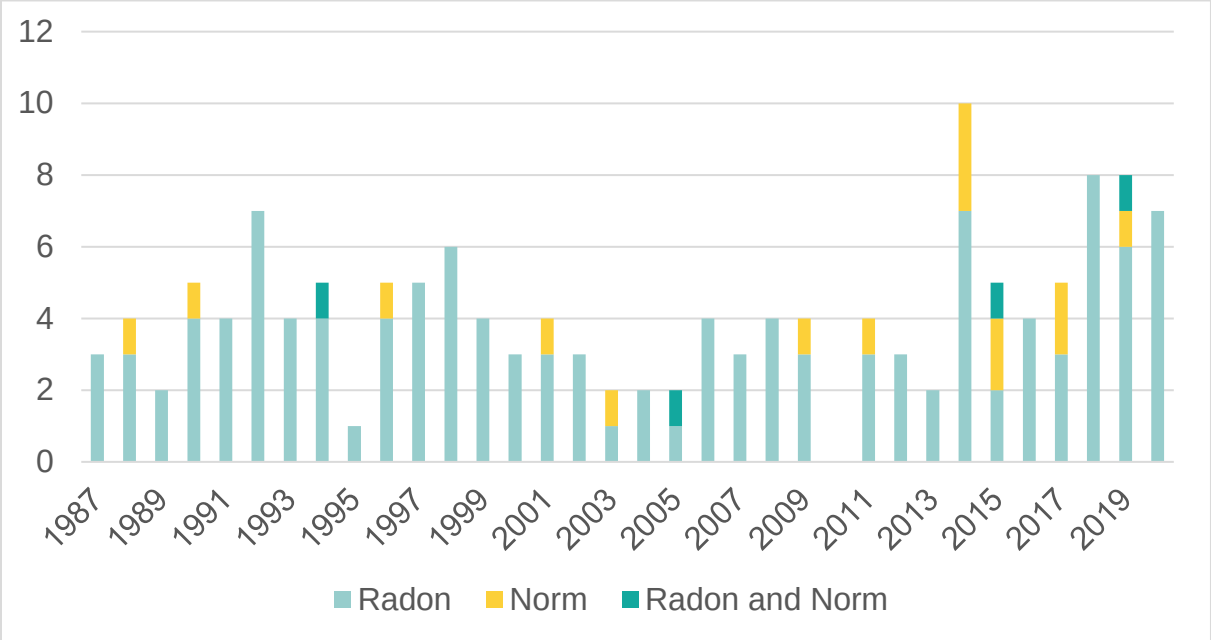

Figure 9 Overview of all the reviewed papers with regard to the topic of the investigation, study design applied and geographic setting

4.1.5 Populations studied

In 87% of the reviewed articles (N = 124) only one specific population was studied, but a few articles looked at two (N = 11), three (N = 5) or more than three (N= 2) populations simultaneously.

In most of the articles the population under observation was the general public affected by radon and/or NORM (N = 114), this group encompasses ‘property owners’, ‘tenants’, ‘households’ and ‘citizens’ and ‘homes’. Much less focus has been paid to the attitudes, risk perceptions, behaviour and opinions of the other groups such as the school-population (N= 16), health professionals (N = 10) and experts (N =10) (for details see Table 3).

Table 3 - Types of the populations studied in the reviewed articles

Population	Terms used to describe	Number of Studies
General public	Public Citizens Residents Property owners (e.g. house) Tenants Households Homes	114
School population	Students Schoolchildren Educators School staff Schools	16
Health professionals	Health professionals	10
Experts	Experts Scientists	10
Parents or guardians	Parents or guardians	5
Other	Operators (oil field, water hauling truck) Media (e.g. articles) Government employees Shop owners Manual laborers Environmentalists Tourists Radon activities Roma (non-permanent residents) Real estate industry representatives Landowners Local authorities Managers childcare centres Daycare centres	15

4.2 Ethical aspects

This section focuses on the aspects that are directly or indirectly linked with the way ethical approval has been reported in the reviewed articles. For the selected publications on social science research related to radon or NORM, we consider the following questions:

- Has ethical approval been obtained for the study and who issued the ethical approval?
- How was privacy handled in general (e.g. anonymity of respondents, how the data was managed etc.)?
- Which possible conflicts of interest have been alluded to by the authors?

4.2.1 Ethical approvals of the studies

The systematic analysis showed that out of 141 articles published in the period between 1987 to 2020, only 35 articles reported that they had received ethical approval from an ethical research committee (See Figure 10). As expected from the introduction of more stringent guidelines, studies published after 2013 are more likely to report that ethical approval for the research was received. Between 1987 and 2013, only ten of the published articles referred to ethical approval from a total of 97 articles. While there were seven SSH articles published in 2020 and five of them report ethical approval.

It is interesting to notice that some protocols have been developed and later approved with collaboration of researchers with investigated communities. For instance, the DiNEH survey was developed with Navajo community member participation, field-tested by bilingual Navajo community environmental health workers (CEHWs), and approved through Navajo Nation and University institutional review boards (deLemos et al., 2009). Written approval was also taken from the local education authority in study of (Nursan, Muge, Cemile, Pinar, & Sevin, 2014).

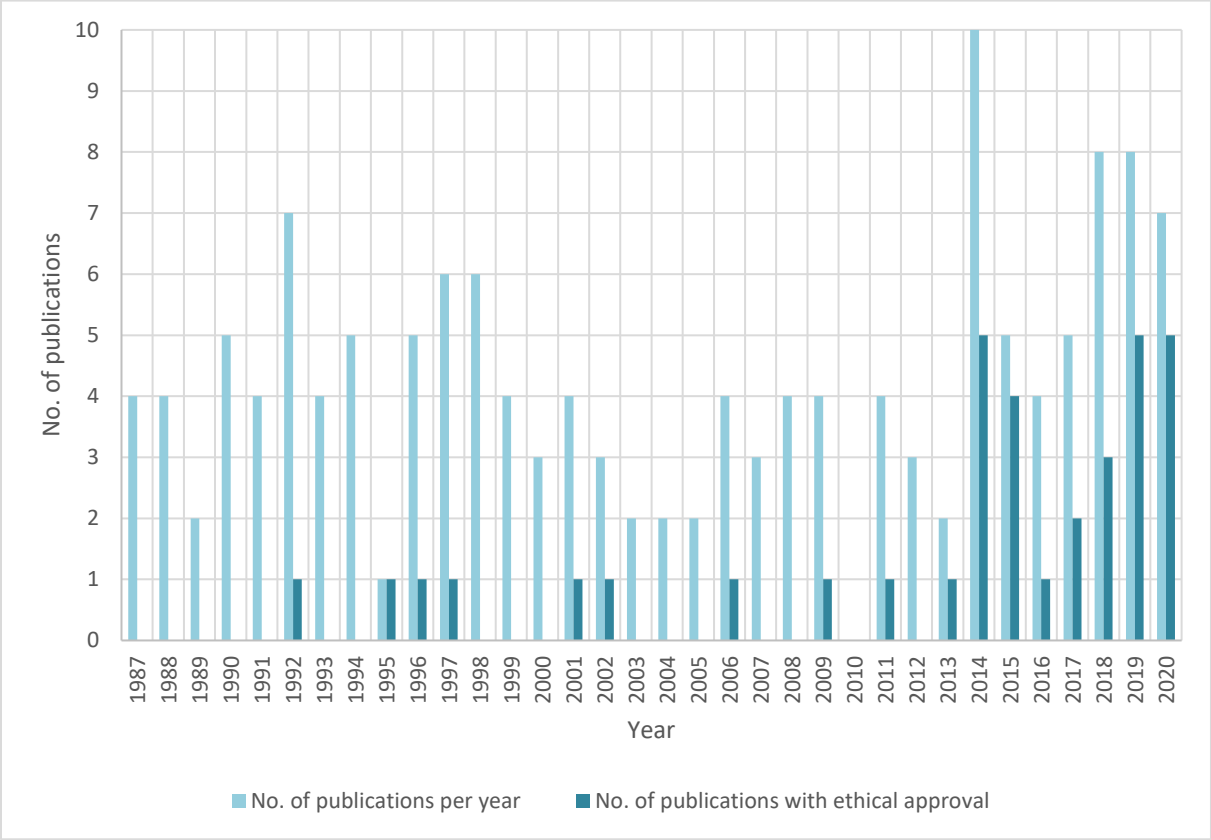

Figure 10 Number of SSH publications related to radon and/or NORM per year and those reporting ethical approval

Most of the received ethical approvals, either for the study or for the data collection protocols were issued by research ethical committees at the universities where the study was conducted. For example: the University of Kentucky Medical Institutional Review Board (Butler, Rayens, Wiggins, Rademacher, & Hahn, 2017), the Rutgers University Human Subjects Review Board (Burger, Martin, Cooper, & Gochfeld, 1997), the Ethical Board at Sakarya University and approval was also received from the local education authority (Nursan, Altun, & Dede, 2011), the University of Vermont Research Protections Office under Instructor's Assurance for the Public Health Projects course at the College of Medicine

(Evans et al., 2015), the Rowan University institutional review board (Gleason, Taggert, & Goun, 2020), the University of Ottawa's Institutional Review Board (Khan et al., 2018), the Emory University's Human Investigations Committee (Kilpatrick et al., 2002), the Montana State University institutional review board (Larsson, 2015), the University of Iowa Institutional Review Board and the Siouxland Institutional Review Board (Levy et al., 2015), the University of Florida's Institutional Review Board (Losee, Shepperd, & Webster, 2020), the Ethical Board at Sakarya University (Nursan et al., 2014), the Seton Hall University institutional review board (Nwako & Cahill, 2020), the University of Pittsburgh's Institution Review Board (Rickenbacker, Vaden, & Bilec, 2020), the University of Louisville Institutional Review Board (Zierold & Sears, 2015), the Institutional Review Board of the University of Louisville (Zierold & Sears, 2014; Zierold, Sears, & Brock, 2015).

Some articles report approvals by bodies outside the universities, such as a study of Momin et al. (2018), which was reviewed and approved by the Center for Disease Control Institutional Review Board (protocol #6491) and the Office of Management and Budget (OMB #0920–1051) in the United States.

Some studies also refer to the Helsinki Declaration regarding medical experimentation on human subjects. For instance a study of Hazar et al. (2014) referenced Helsinki Declaration and in addition mentioned approval by the ethics committee, Deputy of research, Tehran University of Medical Sciences. Other investigations had simply reported a compliance with ethics guidelines, for instance Khan and Chreim (2019) complied with Canada's Tri-Council ethics guidelines, without checking for validity of the claim.

Some studies refer to a general research approval rather than a specific ethical approval. For instance, the study of B. B. Johnson (2017) reports that the project received institutional review board approval. Similarly, the study of Jones, Foster, and Berens (2019) was reviewed by the institutional review boards at both the CDC and ICF International (contractor who conducted fieldwork for the study) and determined to be exempt.

There were also some compromises reported related to the ethical aspects of the research. For instance the research design for the study of Smith, Desvousges, and Payne (1995) was according to the authors "*a compromise, reflecting the effects of the initial requirements of the New York State Energy Research and Development Authority's study intended to monitor radon levels in private homes around New York state, the specifications of the agency (i.e., EPA) funding our evaluation of the effectiveness of information programs as part of the formulation of Agency policy on radon, and the need to adjust the design to meet ethical standards for human subjects research.*"

While some studies report that sampling and consent procedures were approved, for instance by the Boston University Medical Center Institutional Review Board for study of Peterson and Howland (1996), others report only ethical information related to informed consent. For instance, a sample of respondents - members of a convenience sample recruited from homeowners in Eugene Springfield, Oregon - has given consent to have questionnaires mailed to them from time to time for research purposes (Hampson, Andrews, Barckley, Lee, & Lichtenstein, 2003). Consent forms and questionnaires were mailed out a week in advance so that the participants would have time to review the materials and complete them before the home visit in study of Hill, Butterfield, and Larsson (2006). In addition, Keller (2011) only reports in her study that informed consent was received by participants. It was noted that also for the follow-up studies an informed consent is needed, for instance in the study of Nissen, Leach, Nissen, Swenson, and Kehn (2012) „*patients were asked to provide informed consent to participate in the follow-up portion of the study*".

Interestingly, some studies report explicitly, that "*No specific informed consent was required because no personal identifying information was collected*" (Levy et al., 2015). Also, Martin et al. (2020) in their article report that the study "*was reviewed and received an exemption from the local Committee on Human Research in Behavioral and Social Sciences (IRB, CHRBSS B06-194). Under the exemption, formal Institutional Review Board (IRB) Committee review was not required, and the project was*

approved under an instructor's assurance. As such, no formal consent was required for participation in the study." In study of Murphy, Peel, Butts, McKenzie, and Litt (2019) the Colorado Multiple Institutional Review Board approved the study for exemption (#14-1362) and "*thus did not require informed consent*."

Selected studies also report specific ethical considerations. For instance in their article Weinstein, Sandman, and Roberts (1990) stated: "*ethical considerations prevented us from sending low-threat brochures that downplayed the hazard*" (p. 797) and "*Ethical considerations limited the differences that could be created between "high" and "low" conditions.*" (p. 789).

There are also some studies where participants received incentives. For instance, in a study of Cronin, Trush, Bellamy, Russell, and Locke (2020) is reported that: "*Survey participation was voluntary and oral informed consent was obtained from the study participants prior to starting the survey. Once each survey was completed, each participant was compensated with $5 cash and was given a radon information pamphlet*."

4.2.2 Privacy, anonymity and data management

Privacy, anonymity and data management were not reported in the majority of articles, although there were some exceptions:

In the article by Nursan et al. (2014), all parents in the sample received an anonymous self-administered questionnaire, including an explanation about the purpose of the study, advising that they were under no obligation to complete the questionnaire, and explaining that the information obtained would remain confidential. In other cases, participants were assured through an informed consent form that all data would be treated anonymously (Keller, 2011; Khan et al., 2018; Martin et al., 2020; Nursan et al., 2011). Some authors described the anonymization, for instance in a study by Khan and Chreim (2019) they "*assigned a number to each participant to maintain anonymity and excluded identifying information from the quotes*." In an article by Momin et al. (2018) authors described the anonymization process as following: "*To provide anonymity, each participant was assigned a prepopulated number that was used when referring to them during discussion. Written notes included both verbal (e.g., speaker identification by number) and nonverbal cues (e.g., participants nodding in agreement to a statement or anyone exiting and returning to the room). The audio files were transcribed verbatim by a professional transcription service. All potentially identifying information was omitted during transcription (e.g., client names mentioned by Realtors)*".

A few articles referred to privacy, anonymity and data management. For instance, the article by Rickenbacker et al. (2020) reports: "*Some or all data, models, or code generated or used during the study are proprietary or confidential in nature and may only be provided with restrictions (e.g., anonymized data)" The collection of sensitive information about subjects is limited to the amount necessary to achieve the aims of the research, and the deidentified data was only assessed by the research team. Some or all data, models, or code generated or used during the study are proprietary or confidential in nature and may only be provided with restrictions (e.g., anonymized data). List items and restrictions: Ambient air quality data is publicly available; Individual quality of life survey results are confidential; Individual residential indoor air quality data are confidential*."

The full details of data management are not provided in any study, and usually refers to technical aspects, such as: "*the data from each completed survey was automatically collected and stored online by Qualtrics*" (Torres, Yadav, & Khan, 2017a) or "*For smoking quitters: The answers were entered into a bespoke Access database, using double entry and record comparison to ensure data accuracy*" (Denman et al., 2009).

4.2.3 Conflicts of interest

In most of the studies the question of conflict of interest is not addressed. In the few studies where authors were asked to specify potential conflict of interest, all authors claim not to have any conflict.

4.2.4 Discussion and conclusions

Some general points can be picked up from this analysis for further elaboration:

- There is a need to follow up on the new ethical requirements that are likely to receive more focus in the future (e.g. data protection, privacy, conflicts of interest)
- Implications of radon measurements on privacy, house prices, health insurance
- The balance between open science, sharing data and privacy and anonymity of participants
- Ethical aspects of citizen science
- Changes in ways research data can be used (beyond those planned for in the original research)

These questions will be topic of further research and reflection as part of the RadoNorm project, but some few points and examples can be mentioned here.

As specified in the section 2.4, '*researchers should be as objective as possible'* in doing their research, being aware of (and trying to avoid) possible bias. Bias in that sense can be ethnocentricity or gender-related, but it can also be triggered by anticipated (expected) results and competition in the 'research arena'. However, the question of whether social sciences and humanities research is allowed to be influenced by normative views on the social reality under investigation and/or should refrain from making normative claims about that social reality as part of the research is an open ethical question in itself in research ethics related to SHH research. In the field of Radon and NORM, this question is relevant and requires further reflection in general, and particularly as part of the RadoNorm project, and a meaningful distinction is to be made between the application fields of Radon and NORM in that sense. While the occurrence of Radon is a natural phenomenon as such, which means questioning its justification is meaningless, practices resulting in increased radiation exposure may trigger conflicting opinions on their justification in themselves. Consequently, from a research ethics perspective, the question is raised whether researchers aiming to maintain objectivity in their research should refrain from critically questioning these practices as such or whether it would be precisely their moral responsibility to raise awareness or highlight these issues and formulate these questions as part of their research. The following three examples may illustrate this:

- Should a researcher working in the area of Radon openly criticise poor building construction (motivated by commercial gain) resulting in (unknown) elevated radon exposure levels?
- Should a researcher doing research engaging Radon spa visitors make statements about the justification of Radon spas as such, taking into account potential health risks (rather than benefits)?
- Should a researcher focussing on the topic of NORM in the cement industry make statements about the ecological burden of the cement industry in itself?

Key ethical aspects for further elaboration:

- Follow up on new requirements (e.g. data protection, privacy, conflicts of interest)
- Consider implications of radon measurements on privacy, house prices, health insurance
- The balance between open science, sharing data and privacy and anonymity of participants
- Recognise ethical aspects of citizen science
- Changes in way the research data can be used (beyond that planned for in the original research)

4.3 Quantitative methods

In the following section we will focus on articles with a quantitative design. These articles are characterized by numerical data and statistical analyses. First, the sampling techniques and recruitment modes will be described. Then the investigated constructs in the articles and their psychometric properties will be described and assed. Finally, we will present some reflections on the findings and recommendations for quantitative methods in research.

4.3.1 Sampling

When researchers want to draw inferences about a larger population, they need to select and recruit a smaller group from this population first. Most articles in this review employed a single sampling technique (N=92), but there were also some that used two (N= 13) or three (N = 3) different sampling techniques.

Among the sampling methods that were employed within the reviewed articles, probability sampling (random or systematic) was used in 49 studies, non-probability sampling in 63 and in 13 articles no information was given on how participants were sampled for at least one of the populations under observation.

After random sampling (N = 47), convenience (N= 39) and purposive (N = 13) sampling were the most common. However, several articles were hard to categorise as distinctions between convenience and purposive modes of sampling were not clear (N = 3). The reason for this is that we observed a number of flaws related to the use of correct terminology by authors when describing their sampling techniques. For instance, the term “random sampling” was used in 36 articles. The remaining 59 articles, 40 of which employed purposive or convenience sampling, had to be categorized by the master coders based on the description of the sampling procedure (see explanation for data extraction procedures in 3.3.2). For instance, Rahman, Faheem, Rehman, and Matiullah (2006) described their sampling method as random, but based on the description, we re-categorized it to “convenience sample”: "*random interviews were carried out in shopping centres, parks, bus stops, etc*.”.

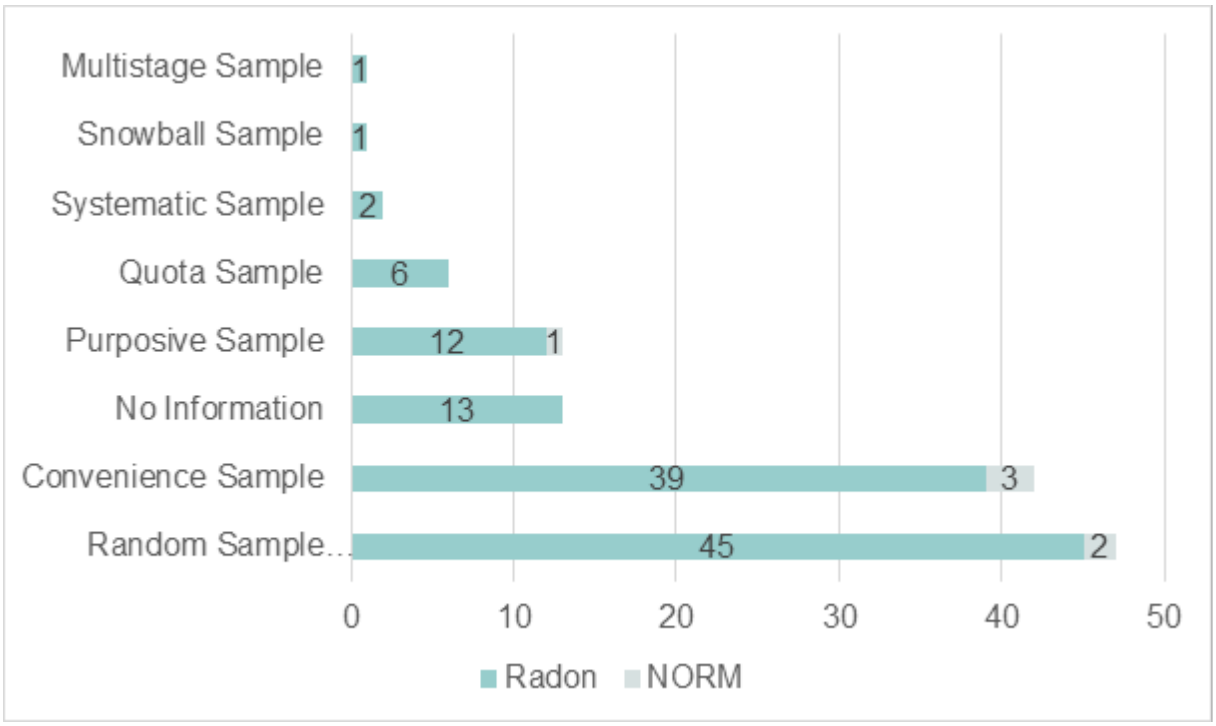

Figure 11 Sampling methods used in the quantitative articles

Correct use of terminology is important to allow readers and the reviewers to correctly evaluate the article and interpret the findings. Findings from an article in which a probability sampling was used could potentially be generalized to the whole population, however only in 19 articles did authors state that the study is representative. Most often there was no information on the generalizability of the results (N= 65) and in 24 studies the authors explicitly stated that the sample is not representative for the whole population. For the studies focused on NORM, authors didn't state that sample was representative in any of the articles.

4.3.2 Mode of recruitment

A variety of recruitment modes have been used in the reviewed articles with letter and telephone being the most common (Figure 12).

Most participants were recruited through post mail (N = 35), followed by telephone (N = 29) and face-to-face recruitment (N = 22). Other recruitment modes included: email (N = 7), social media (N = 3), and media advertisement (N = 2). In 23 articles a multi-mode approach was used, meaning that several modes were combined in order to maximize participation.

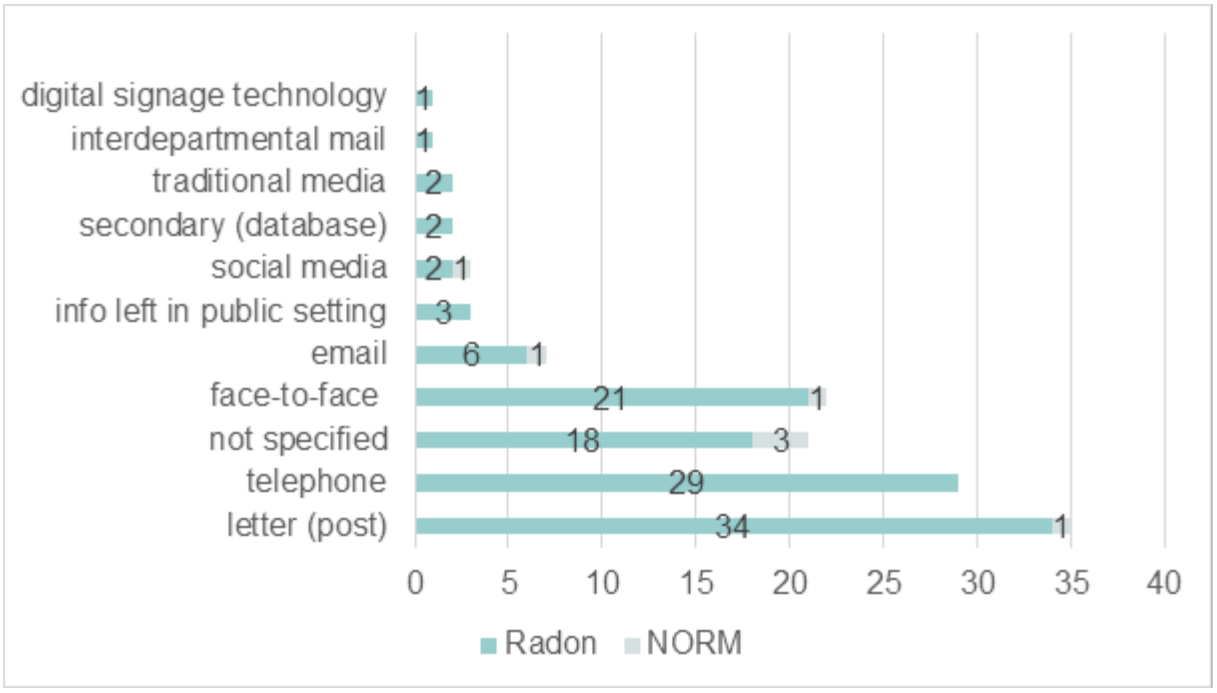

Figure 12 Modes of recruitment used in the quantitative articles

4.3.3 Variables and items where psychometric properties have not been reported

This section contains an overview of variables used in these quantitative empirical studies on radon and one on NORM. Most of the variables used in these studies are single items and exam-style indices, whereas composite variables measured with multiple items and for which reliability has been reported, will be discussed in the next section.

It should be noted that some studies report having used concepts that are typically measured as composite constructs (e.g. subjective norms, attitudes towards radon testing); however, unfortunately, they do not report the items used. Likewise, for some composite constructs reported to have been used in studies on radon, reliability and validity considerations are not reported, while it is possible that such

analyses have been done. It should also be noted it was not always clear whether some of the variables in the reviewed articles were dependent or independent, in some articles some variables were used as both independent and dependent. Therefore, we will provide an overview of all the variables without making this distinction. However, the flowcharts in the Figures 13, 14, 15, 16 in the sub-sections 4.3.3.1, 4.3.3.4, 4.3.3.10 and 4.3.3.11 present the connections between the variables. Table 4 provides an overview of this section's content to assist navigation.

Table 4 - Overview of the variables presented in this section

Category	Variable	Page nr
Socio-demographic variables	• Gender/Sex • Education • Age • Income • Smoking status • Location • Home ownership status • Age of house • Years spent in residence • Basement as a living space • Planning to move from current residence • Children living in the residence • Duration of living near a coal ash site • Work in NORM industry	36
Location and property value	• Attitudes and feelings about state and local economics • Perceived effect of radon on property value • Impact of radon on home buying behaviour	40
Awareness and knowledge	• Awareness of radon • Radon risk area awareness • Radon knowledge • Confidence in own knowledge • Awareness of produced water handling and content – personal • Awareness of produced water handling and content – societal • Salience of radon	41
Risk perceptions	• Radon susceptibility/threat • Perception of radon as a serious health problem • Likelihood of exposure to radon • Radon risk perception – personal • Radon risk perception – societal • Societal comparison • Scientists' perception of radon risk as an environmental hazard • Synergistic risk perception of radon and smoking • Perception of NORM as a safety risk • Experts' opinion on rank of risk of different stakeholders	46
Acceptability of risk	• Acceptability of radon risk • Recall of information • Acceptance of information	53
Health-related variables	• Importance given to radon by family doctors • Health priorities • Health behaviours • Self-reported health status • Experience with cancer in the family • Contact with health provider	54

Trust and perceived competences	• Competences of authorities managing radon risk • Trust in state officials and oil operators • Competence of state official and oil operators	55
Emotions	• Emotional response to radon	56
Communication and engagement	• Talking about radon • Sources of information about radon • Trust in radon information sources • Need for information • Information processing indicators • Radon information avoidance • Community engagement • Knowing who to contact to report water spill	56
Measuring/testing for radon	• Measured radon • Radon testing • Perceived ease/difficulty of radon testing • Reasons for testing/not testing • Sources for radon testing recommendations • Subjective norm • Knowing other people who tested for radon • Attitudes towards radon testing in schools	58
Remediation/ mitigation of exposure	• Radon mitigation response/practice • Perceived ease/difficulty of mitigation • Remediation concern • Radon mitigation intentions • Perceived benefits and efficacy of remediation measures • Perception of remediation • Financial resources – ability to afford repairs • Cost of reducing radon in home	63

4.3.3.1 Socio-demographic background variables

The main categories of the socio-demographic variables that have been measured in the radon and NORM studies are presented in the Figure 13.

Gender/Sex

The majority of the studies have two response categories: “Male”, ”Female”. However, the response categories should follow current recommended practice in social sciences and include the options: “Other” and “I prefer not to say”. Though, because of the limited number of respondents choosing the latter categories, one should be careful to make inferences.

Education

Most studies used 3-4 education categories. Often used categories are lower (e.g. primary or lower secondary), intermediate (e.g. higher secondary) and higher education (e.g. post-secondary university and post-university) levels. However, depending on the school system of particular countries, the answering categories should be adapted. In comparative studies it may therefore be better to measure the number of years a respondent took fulltime education.

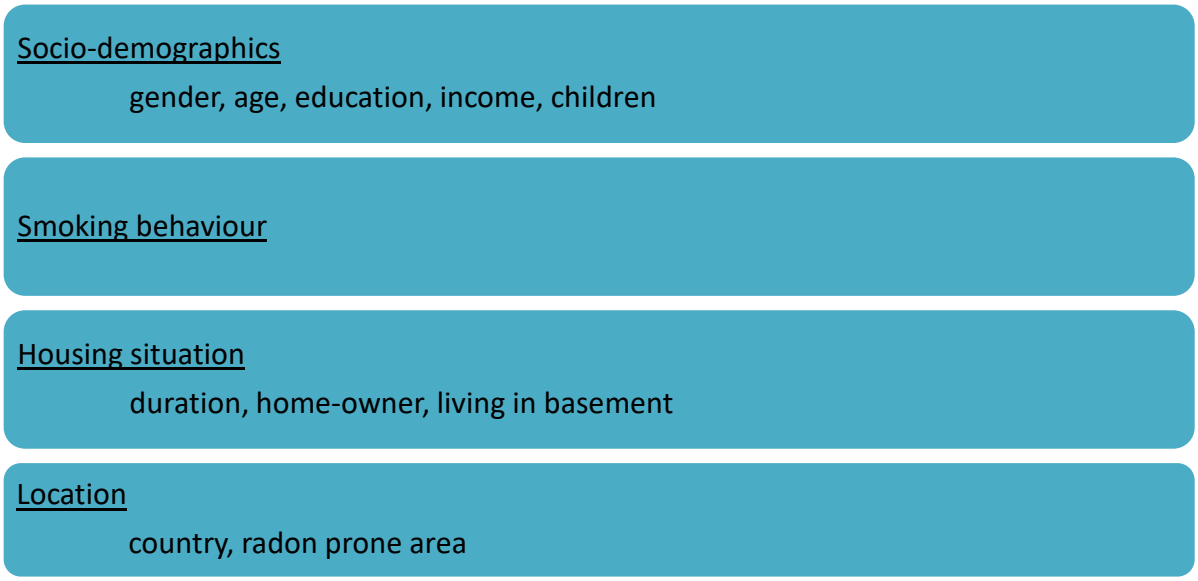

Figure 13 Radon/NORM explanations or controls: systematic overview of the variables

Age

The age of respondents can be asked either as their year of birth, exact age or age category. We recommend the former, as it can then be processed into any categories and it then enables comparability with other studies in future analyses. However, if age categories are used they should be theoretically justified.

Income

Income is typically measured with several categories and, if included, should be justified and adapted to the country. In some articles income measures are used for the calculation of social economic status (SES) among other variables such as education. In some countries asking to disclose income can be highly sensitive, so it is better to ask respondents to select the income range.

Smoking status

Examples of scales used to measure smoking behaviour are given below:

Gleason et al. (2020):

Not at all: not smoking currently and no history of 100 cigarettes or more; Some day; Every day

Rather than asking respondents, *Rinker et al. (2013)* constructed the above categories based on the answers given to two questions:

Q: “Have you smoked at least 100 cigarettes in your entire life?” (yes/no)

Q: “Do you now smoke cigarettes every day, some days, or not at all.”

Halpern and Warner (1994); Rinker et al. (2013) used the following answering categories:

Current smoker; Former smoker; Never smoker

Weinstein and Sandman (1992a) used the following answering categories to capture the frequency of smoking:

Q: ”How many cigarettes a day do you smoke?” :

None; less than a pack; more than half a pack

Point of attention: The question wording above is somehow ambivalent because different package sizes exist.

Poortinga, Cox, and Pidgeon (2008); Hahn, Rayens, Kercsmar, Robertson, and Adkins (2014) used 2 answering categories:

Q: “Do you currently smoke cigarettes, even just once in a while?”:

Yes (Smoker); No (Non-smoker)

Poortinga, Bronstering, and Lannon (2011) added to the above answering scale the category “Refused” to allow respondents to refuse answering this question.

Hahn, Rayens, Kercsmar, Robertson, et al. (2014) also accounted for passive smoking:

Q: “Is there currently a smoker living in the home?” (yes/no)

Point of attention: The question wording above is somehow ambivalent because a smoker living in the home does not necessarily smoke indoors.

Location

Torres, Yadav, and Khan (2017b) included a question for location:

Q: “Please select the country in which you reside currently. “

Home ownership status

In a number of studies *(e.g. Cronin et al., 2020; Peterson & Howland, 1996; Poortinga et al., 2008)* home ownership status is assessed with only two answering categories: “yes” or “home owner”, and “no” or “renter or tenant”. *Gleason et al. (2020)* and *Poortinga et al. (2011)* added therefore the category “Other”.

Poortinga et al. (2011):

Yes; No (rented); Other

In addition, *(Gleason et al., 2020)* specified the category “Other” with examples:

Own; Rented; Other (e.g. staying with family or friends at no cost, or living in a group home)

Point of attention: It is important to include other situations e.g. living with family members friends without paying rent when investigating home ownership status.

Age of house

Desvousges, Smith, and Rink (1992) used the following categories:

Built before 1940; Built between 1940 and 1970; Built after 1970

Years spent in residence

F. R. Johnson and Luken (1987) included the question:

Q: “How many years have you resided in the tested home?“

Basement as a living space

Desvousges et al. (1992) included a question on the use of the basement as a living space:

Q: “Does your house have a basement that is used as a living space?” (yes/no)

If this variable is used, the option “I don’t know” should be added.

Peterson and Howland (1996) included a variable for the amount of time family spent in basement:

Q: “Average hours per week spent in a basement or below grade area of one’s residence?”: Less than 5 hours; More than 5 hours; Don’t know

Planning to move from current residence

Peterson and Howland (1996) inquired whether respondents planned to move in the next year:

Yes; Maybe; No; Don’t know

Children living in the residence

Peterson and Howland (1996) enquired about the number of children in household, *Poortinga et al. (2008)* asked about the absence/presence of children in household (Yes/No) and *Weinstein and Sandman (1992a)* asked whether there were children under 10 years age in residence.

Duration of living near a coal ash site

In the article related to NORM, *Zierold and Sears (2015)* measured the duration of residing near a coal ash power plant: <5years; 5-10 years; 11-15 years; 16-20 years; >20 years

Work in NORM industry

Torres et al. (2017a) included three questions related to working in the oil industry:

Q: “Do you work or have you worked in the oil industry in North Dakota?“ (yes/no)

Q: “Do you know someone that works or has worked in the oil industry in North Dakota?” (yes/no)

Q: “As part of your daily job, do you have responsibilities directly related to oil production and produced water management or do you work in one of the areas listed below?” : Emergency management in ND OR Key response partner (i.e. public health, law enforcement, fire, emergency medical services) (yes/no)

4.3.3.2 Location and property value

Attitudes and feelings about state and local economics

Torres et al. (2017a) included two questions about state and economy:

Q: "How satisfied or dissatisfied would you be living or investing in North Dakota?": Extremely dissatisfied; Somewhat dissatisfied; Neither satisfied nor dissatisfied; Somewhat satisfied; Extremely satisfied

Q: "Areas where produced water is stored or transported are likely to be unattractive to new residents, business development, and tourist": Strongly disagree; Somewhat disagree; Neither agree or disagree; Somewhat agree; Strongly agree

Point of attention: The problem with the last question is that there are three questions in one. Respondent might completely agree that it would be unattractive to businesses but could think it would still be attractive to tourists, or some other combination. Answering this question would thus be difficult, for this reason it is better to split the question up in three different ones or to make a grid.

Perceived effect of radon on property value

Smith et al. (1995) investigated respondents' perception of the impact of the presence of radon in house on the potential selling of the property:

Q: "Selling homes with high radon levels is very difficult"

Answers were given on a 5 point Likert agreement scale, subsequently dichotomised as 1 for strongly agree or agree, and 0 for else.

Weinstein and Sandman (1992a,b) also investigated the effect on home sales as % decrease in home value if home left at original level vs. level reduced to very low. The formulation of the questions in *Weinstein and Sandman (1992b)* is:

Q: "How much do you think your home value would be affected if you have a radon problem?"

Q: "How much do you think your home value would be affected if you have a radon problem but you take action that gets rid of it?"

Answering categories were: 1=value up; … ; 5=down over 30%

Impact of radon on home buying behaviour

Neri et al. (2018) asked respondents whether:

Q: "radon health issues impacted home-buying process?" (yes/No)

Neri et al. (2018) asked a number of related questions in that regard:

Q: Real estate agent discussed radon with homebuyer (Yes/No)

Q: Paperwork signed by buyer/seller related to radon testing (Yes/No)

Q: Buyer received radon brochure during inspection/closing (Yes/No)

Johnson and Luken (1987) asked the question whether the respondent tends to acquire a great deal of information before making consumption decisions.

Point of attention: The question wording above is somehow ambivalent because 'a great deal' may have different meanings for the respondents.

4.3.3.3 Awareness and knowledge

Awareness of radon

Most studies *(e.g. Cronin et al. 2020, Poortinga et al. 2011)* use the question asking whether respondents had ever heard of radon.

Point of attention: It remains to be seen if the answers to this question are meaningful because 'having heard of' is a very broad category.

Poortinga et al. (2011):

Q: "Had you heard of radon before this interview?": Yes; No; Don't know

Larsson et al. (2009) added to the "I don't know" category the refused option: "I don't know/refused".

Neri et al. (2018) and Denu et al. (2019) enquired about awareness of "radon related health issues":

Q: "Are you aware of the health risks associated with exposure to radon?"

Radon risk area awareness

Poortinga et al. (2008) assessed awareness of exposure to indoor radon as follows:

Q: "Do you believe that your home is in a radon area?" (yes/no)

Poortinga et al. (2011) reformulated the question and add "Don't know" as answering category:

Q: "As far as you know, do you think you live in an area affected by radon?": yes; no; don't know

Radon knowledge

Radon knowledge is typically assessed with exam style questions, whereby a knowledge variable is constructed as the sum of correct answers given to a number of true/false questions.

Nwako and Cahill (2020) use the following radon knowledge items, with possible answers True/False:

- Radon has a strong odor
- Radon exposure is linked to lung cancer
- Radon is a radioactive gas
- Radon is invisible
- Radon is a solid at room temperature
- Radon is a gas at room temperature;
- Radon occurs naturally in rocks and soils
- Radon levels are usually higher in the attic than the basement
- About 1 in 15 homes in the U.S. have elevated radon level
- Being exposed to radon increases smokers' chances of developing lung cancer
- Radon is the leading cause of lung cancer in the U.S. among non-smokers
- Testing for radon is the only way to determine if a home has an elevated radon level

Cronin et al. (2020) use the following True/False statements concerning radon:

- Radon is an invisible gas that can become trapped in your home
- You live in an area with typically high indoor radon
- Breathing in radon gas can cause lung cancer
- There is nothing that can be done to rid your home of radon

Desvousges et al. (1992) used multiple-choice questions covering general knowledge about testing, health risks, and mitigation in the follow-up surveys. These questions referred to:

Q: "Where does radon in homes come from?"

Q: "Which of the following best describes radon?" (e.g. radon occur naturally and has no odor)

Q: "When radon is measured in a home, which of the following will affect the most?"

Q: "How can one test for radon?"

Q: "When do health problems from radon usually occur?"

Q: "What kind of health problems are high levels of exposure likely to cause?"

Q: "What can homeowners do to reduce high radon levels in their home?"

Hahn et al. (2014) used 6 items:

- Radon exposure is unhealthy
- Radon can cause Lung cancer: true
- Radon can cause Other cancers: true
- Radon can cause Arthritis: false
- Radon can cause Asthma: false
- Radon can cause Headaches: false

Ryan and Kelleher (1998) used 12 true/false items (the statements listed below are correct, in the questions some were formulated as not correct):

- Radon is a gas
- Radon does not have a distinct odour
- Radon levels can vary in nearby houses
- Radon levels vary with the season
- Sealed windows increase the amount of radon
- Radon is not from Industrial pollution
- Radon moves from soil to air
- Radon enters through cracks in walls and floors
- High radon levels do not raise skin cancer risk
- Health effects of radon do not show for years
- Radon does not irritate eyes or throat
- High radon levels raise lung cancer risk

In the study by *Golding, Krimsky, and Plough (1991*) the statements were:

- radon is a colorless, odorless, tasteless gas
- radon comes from the natural breakdown of uranium
- exposure to radon can cause lung cancer
- radon levels are generally higher indoors
- the amount of radon depends largely on soil
- position of ventilation and techniques
- radon levels tend to be higher in basements
- elevated levels can be reduced by various forms
- radon can be measured by inexpensive screening
- how smoking affects the risk of radon exposure
- variations in radon levels over the year
- the effects of operating furnaces and appliances on indoor radon levels

Kennedy, Probart, and Dorman (1991) measured radon knowledge with the following index (highest score = 9):

- heard of radon
- knew radon did not increase risk of skin cancer
- knew it increased risks of lung cancer
- knew the health risks were cumulative
- knew radon was a gas
- realized radon has no distinctive odor
- knew could enter through cracks in foundations
- knew it was caused by decay of a radioactive element

Peterson and Howland (1996) used the following items (treated independently in analyses):

Q: Most radon in homes comes from: Industrial pollution; Uranium in soil; Home appliances; Don't know

Q: Which best describes radon?: No odor; Slight odor; Do not know

Q: First aware radon could cause health problems: Today; Less than a month ago; Between one and six months ago; More than six months ago

Q: Can exposure to high levels of radon cause lung cancer?: Yes; No; Do not know

Q: When radon is measured in a home, the level will: Depend on time of year it's measured; Not depend on time of year it's measured; Don't know

Q: People's risk from radon exposure: Increases if they smoke; Stays about the same if they smoke; Don't know

Q: Radon levels are usually higher in the: Basement or lowest floor/Don't know

Q: To determine whether there is a high level of radon in your home requires: An inexpensive screen test administered by homeowners; Expensive radiation equipment administered by trained professionals; Don't know

Point of attention: It can be noticed that one of the questions above uses the attribute “expensive/inexpensive” in knowledge questions, although respondents may have different perceptions of what can be considered as expensive.

In the longitudinal study by *Smith, Desvousges, Fisher, and Johnson (1988)* the following items were used in the Baseline Survey and Follow-up survey*:

1) Is radon a
   a) Colorless, odorless gas
   b) Or a chemical given off by radar equipment
   c) Don't know
2) Is radon caused by
   a) Industrial pollution
   b) Or the natural breakdown of uranium
   c) Don't know
3) Are high levels of radon likely to cause
   a) Minor skin problems
   b) Lung cancer
   c) Don't know

4) Does the amount of radon in a building depend mainly on the
   a) Type of machines or appliances in it
   b) Or the amount of radon in the underlying soil
   c) Don't know
5) Do the risks from radon exposure
   a) Increase the longer you are exposed
   b) Or stay the same no matter how long you are exposed
   c) Don't know
6) When radon is measured in a building, the level will
   a) Depend on the time of year it is measured
   b) Not depend on the time of year it is measured
   c) Don't know
7) Are radon levels usually higher in the
   a) Basement or lowest floor
   b) Or the highest floor
   c) Don't know
8) Will people's risk from radon exposure
   a) Increase if they smoke
   b) Or stay about the same if they smoke
   c) Don't know
9) Can the level of radon in a home or building be reduced by
   a) Increasing the amount of air ventilation
   b) Or by adding attic insulation
   c) Don't know
10) Are household appliances such as furnaces or clothes dryers likely to
   a) Increase the amount of radon by lowering inside air pressure
   b) Or decrease the amount of radon by venting it outside
   c) Don't know
11) Would the effectiveness of ways to reduce radon in homes or buildings
   a) the same for all housing or building types
   b) Or depend on the features of each home or building
   c) Don't know
12) Will drawing radon away from the home or building before it enters
   a) Usually involve several thousand dollars and an experienced contractor
   b) Or depend on the features of each home or building
   c) Don't know

Follow-up Survey only (all items marked with * were included in the follow-up survey):

- High levels of radon exposure: a) Will irritate the throat and eyes; b) Or will not irritate the throat and eyes; c) Don't know
- When radon is measured indoors, the level; a) Will depend on whether the house is closed up; b) Or will not depend on whether the house is closed up; c) Don't know
- Are people's risk from one year of radon exposure: a) Much lower than their risk from a lifetime exposure; b) Or about the same as their risk from a lifetime exposure; c) Don't know

Evans et al. (2015) asked people how confident they were in their knowledge of ionising radiation: 1 = not at all confident; … ; 5 = highly confident

Smith et al. (1988) tested namely respondents' ability to correctly use the risk charts provided in information brochures to:

- Correctly locate (in the follow-up survey) his reading on the risk charts provided in the brochures designed by the project or in the EPA Citizen's Guide.

- Correct advice to a hypothetical neighbour with a specified radon reading on the timing of recommendations for mitigation activities.

Confidence in own knowledge

Evans et al. (2015) measured confidence in their own knowledge of ionising radiation using a Likert-style scale ranging from 1 (not at all confident) to 5 (highly confident).

In their study among family medicine residents, *Sanborn et al. (2019)* included a question regarding their confidence level in answering patients' questions about radon, using the answering categories:

Not at all confident; Somewhat confident; Moderately confident; Quite confident; Very confident

Awareness of produced water handling and content - personal

Torres et al. (2017) included four questions about awareness to NORM in water:

Q: "How familiar are you with the processes of storage and transportation of produced water?":

Not at all familiar; Slightly familiar; Moderately familiar; Very familiar; Extremely familiar

Q: "How aware are you with the content of produced water? (e.g. chemicals additives and contaminants)": Not at all aware; Slightly aware; Somewhat aware; Moderately aware; Extremely aware

Q: "How familiar are you with natural radioactive material and its effects on human health?":

Not at all familiar; Slightly familiar; Moderately familiar; Very familiar; Extremely familiar

Q: "Did you know that produced water might contain levels of natural radiative material?" (yes/no)

Awareness of produced water handling and content – societal

Torres et al. (2017) also included three questions, with the same answering categories, to measure whether the participant who work in the oil field perceives others to be aware:

Q: "Based on your experience, how aware do you think the general public is about produced water risks in North Dakota?"

Q: "Based on your experience, how aware do you think the operators in the oil field are about produced water risks in North Dakota?"

Q: "Based on your experience, how aware do you think the hauling truck operators are about produced water risks in North Dakota?":

Not at all aware; Slightly aware; Somewhat aware; Moderately aware; Extremely aware

Salience of radon

Smith et al. (1995) investigated to what extent was radon a priority:

Q: "Radon may be a problem, but I haven't paid much attention to it because there are more important things to deal with"

Answers were measured on 5 Point Likert agreement scale, subsequently dichotomised as 1 for strongly agree or agree, 0 else.

Weinstein and Sandman (1987) enquired respondents' frequency of thinking about radon.

4.3.3.4 Risk perceptions

Risk perceptions are commonly investigated in the field of radon and NORM. The diverse risk-measures are presented bellow and summarized in Figure 14.

Radon susceptibility / threat

Peterson and Howland (1996) used 4 items to measure personal susceptibility to health risks of radon:

These questions will help us understand how people arrive at decisions about radon. Please select the one answer that best describes your opinion:

- I have not been exposed to radon in my home because I live above the first floor
- No one in my neighbourhood has a radon problem that I know of
- I have not been exposed to radon in my home because my home/apartment was built recently
- Non-smoking status protected me from health problems due to radon

Answering scale: 5-point Likert:

1=strongly agree; 2=agree; 3=neither agree, nor disagree; 4=disagree; 5=strongly disagree

Rinker et al. (2013) constructed a variable measuring susceptibility as the sum of two items:

Q: "What do you believe is the likelihood of finding radon in the place you live?":

1 = very unlikely; …; 5 = very likely

Q: "What do you think is the approximate percentage of homes in your area that have radon problems?": 1 = less than 10%; …; 5 = greater than 90%

Johnson and Luken (1987) used 2 items measured on a scale from 0 to 10 to ask respondents about their perception of the:

Q: "Seriousness of the radon problem in their home?"

Q: "Probability of dying from radon?"

Weinstein et al. (1990) measured the likelihood of a radon problem in a randomly chosen house in the community and in the respondent's own home (treated as separate items), highlighting that the latter was more important for radon testing intention than the judgment about community risk:

Q: "Likelihood that a home picked at random in the respondent's community would have a radon problem": 1=no chance; …; 7=certain

Q: "Likelihood that the respondent's own home had a radon problem": 1=no chance; …; 7=certain

Point of attention: The question wording above is somehow ambivalent because the definition of the respondent's community may vary.

Weinstein and Lyon (1999) used a numerical scale to measure two similar items, namely:

Q: "Likelihood of finding radon problems in own home?"

Q: "Percentages of homes with radon problem in the study area?"

Answering categories for both questions were: less than 10%; 25%; 50%; 75%; greater than 90%.

Weinstein et al. (1991) used a similar question and a modified answering scale to measure the perceived likelihood of having a radon level requiring actions:

Q: “How likely it is that your own home has enough radon so that you should do something about it?”:

1 = no chance; … ; 6 = very likely or certain

Sandman et al. (1987) probed respondent’s prediction of radon level in their home relative to the average, measured on the scale: Much higher than average; Higher than average; Average; Lower than average; Much lower than average

Clifford et al. (2012) measured Perceived susceptibility of cancer and perceived severity of cancer (due to radon), both using a 7-point Likert scale.

Johnson and Luken (1987) used 2 items measured on a scale from 0 to 10 to ask respondents about their perception of the:

Q: “Seriousness of the radon problem in their home?”

Q: “Probability of dying from radon?”

Weinstein et al. (1991), Sandman et al. (1987), Rinker et al. (2013) asked respondents about their perception of the seriousness of radon illness.

Weinstein et al. (1991) formulated the question as follows:

Q: "If someone in your home did have negative health effects from radon, how serious do you think they would be?: very serious; serious; somewhat serious; not serious at all

Point of attention: Perceived health problems may vary for the people living in a home.

Ferng and Lawson (1996) measured perception of radon as a problem in residence with: “Yes”, “No” or “Don't know”.

Hazar et al. (2014) used 8 questions to measure “perceived susceptibility”, “perceived severity”, “perceived benefits”, “perceived barriers”, and “self-efficacy”:

Q1.:“It is likely to be exposed to residential radon in Iran”

Q2:.“It is possible that I’m exposed to radon in my house”

Q3.:“It is possible that I develop radon-induced health conditions”

Q4.:“Residential radon exposure can cause serious diseases in me”

Q5.:“I am worried about radon to cause serious illness in me”

Q6.:“It is possible to prevent radon-induced diseases by reducing its level in houses”

Q7.:“I will remain healthy if I’m exposed to radon due to my good general health status and physical resilience”

Q8.:“I can reduce radon in my house with relatively simple and practical actions if necessary

Respondents could answers on a 5 point Likert scale: 1 = completely agree ; … ; 5 = completely disagree

Hampson et al. (1998) measured optimistic bias, participants rated the likelihood of health consequences from each hazard separately for themselves, others in their house, and others in general or in their neighbourhood. All ratings were made on seven-step scales, and there was a “Don’t know” option.

Rinker et al. (2013) formulated the question in a more general way:

Q: "How serious would an illness caused by radon be?"

The variable was then dichotomized in *Rinker et al. (2013)* into those who perceived illness caused by radon to be "serious" or "very serious" versus "somewhat serious" or "not serious at all."

Weinstein and Sandman (1992b) used 3 items to investigate the perceived severity of having high levels of radon in homes. These items related to:

- Seriousness if someone became ill (1-5 answering scale)
- Radon-caused illness being fatal (1-5 answering scale)
- Likelihood of illness if levels were high (1-7 answering scale)

Poortinga et al.(2008):

Q: "How concerned are you about radon gas?": 1 = no concern at all; .. ; 7 = extreme concern

In the above study, the concern scale was dichotomized by recoding the scores 1 to 4 as 0 ("no concern at all" to the scale midpoint) and the scores 5 to 7 as 1 ("moderate concern" to "extreme concern").

Poortinga et al. (2011) used a more detailed question:

Q: "To what extent, if at all, are you concerned about the health risks to you personally associated with radon?" : very concerned ; fairly concerned ; not very concerned ; not at all concerned ; Don't know

The answer options "very concerned" and "fairly concerned" were taken to reflect "concern," while "not very concerned" and "not at all concerned" were taken to represent "no concern."

Weinstein et al. (1990) investigated concern about radon in respondents' home with 2 items:

Q: "How concerned are you about radon affecting you or your family?":

1 = not at all concerned; … ; 5 = extremely concerned

Q: "How serious you think it would be to have a high radon level in their home?":

1 = not at all serious; … ; 5 = extremely serious

Weinstein et al (1990) also assessed community concern about radon:

Q: How concerned are the people you know in your community about radon?:

1 = not at all concerned about radon; … ; 4 = very concerned about radon

In Weinstein and Sandman (1992b) this question was slightly reformulated to:

Q: "In general, do the people you know in your community feel... "

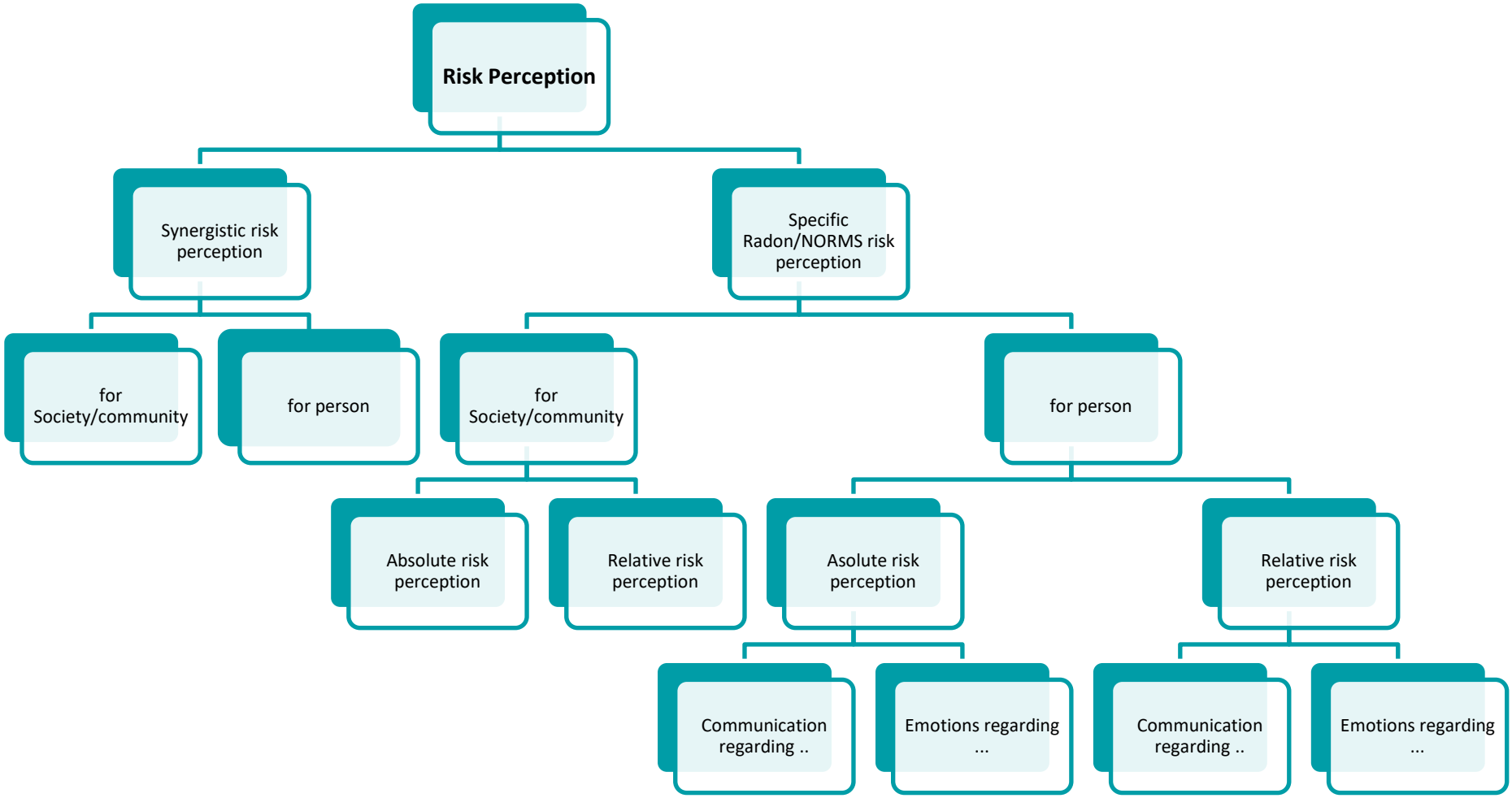

Figure 14 Radon/NORM risk perception: systematic overview of the variables

Sandman et al. (1987) used a series of questions to assess beliefs about radon

Q: Believes other adults in home are concerned

Q: Believes radon is a problem in the community

Q: Believes it is likely that radon is a problem in own home

Q: Knows others who are concerned

Q: Believes other adults in home want test done

Q: Perceives home to be outside the Reading Prong

Q: Has heard people say there is no radon in the area

Q: Belief that one's home value would be adversely affected if the radon level were not lowered

Point of thought: The question wordings above are somehow ambivalent because they use 'multiple referents'

Mazur and Hall (1990) measured concern though the following questions:

Q: "If people have a home radon problem, how important is it for them to act quickly to reduce the radon?

Q: "How concerned are you about radon?"

Q: "How worried are you about radon?

Burger et al. (2000) measured radon severity with the following question on a 5-point Likert scale:

Q: "Radon in homes as severe environmental problem"

Perception of radon as a serious health problem

Peterson and Howland (1996) used 3 items to measure perception of radon as a serious problem and then made an index combining the items:

Q: "I think high levels of radon in [my home could cause lung cancer."

Q: "I think media overreacted to the issue of radon."

Q: "If the state and federal governments were concerned about radon, they would regulate testing and mitigation companies."

Answers for these items were given on a 5-point Likert scale: 1=strongly agree; 2=agree; 3=neither agree, nor disagree; 4=disagree; 5=strongly disagree.

Weinstein and Sandman (1992) inquired about the likelihood (1-7 likelihood scale) and severity (1-7 severity scale) of illness: if no action taken, if the action reduced the radon level. These variables measured also relate to susceptibility and benefits of mitigation actions.

Weinstein and Sandman (1992a) used 3 items to investigate the perceived severity of health effects due to radon. These items related to: Fatality of radon-caused illness, Seriousness if someone became ill from radon, Need to act quickly

Likelihood of exposure to radon

Poortinga et al. (2011) assessed the likelihood of exposure to radon as a 0/1 dummy variable indicated whether people were living in an "actionable" radon-affected area (5% likelihood of exposure at or above the action level) as compared to living in a non-actionable radon-affected area (1–5% likelihood of exposure at or above the action level).

Radon risk perception - personal

Evans et al. (2015) measured perception of radon risk relative to other sources of ionising radiation:

Q: "Select which of the following posed the greatest and least health risk to the respondent": medical imaging tests that use ionising radiation; radon; other natural sources of ionising radiation; nuclear power plants; airplane travel

Sandman et al. (1987) assessed respondents' perception of the seriousness of the measured radon levels in their basement: no problem; slight problem; moderate problem; serious problem; very serious problem

Radon risk perception - societal

Weinstein et al. (1991) asked respondents about the "the radon risk in your area", with answers given as : 1 = no risk of radon ; … ; 4 = high-risk area

Evans et al (2015) measured perception of radon risk relative to other sources of ionising radiation:

Q: Select which of the following posed the greatest and least health risk to the average inhabitant of the region: medical imaging tests that use ionising radiation ; radon ; other natural sources of ionising radiation ; nuclear power plants ; airplane travel

Societal comparison

Weinstein and Sandman (1992) tested (independently) several items related to comparison with others, some of them pertaining to descriptive norms. The items assessed respondent's perception of whether:

- Own level is higher than others
- Others found lower levels (how many)
- Others with lower levels took action
- Others found higher levels (how many)
- Others with higher levels took action
- Concern of others in community (low to high)
- Others suggested you reduce level

Weinstein et al. (1990) investigated respondents' perception of radon level in home, compared to average in community. They asked the respondents whether "their home was likely to have more or less radon than other homes in their community": -2 = much less radon than average for homes in my community; … ; +2 = much more radon than average for homes in my community

The same study also highlighted the reasons for respondents' thinking that the radon level in their homes was higher or lower than average through an open question.

Scientists' perception of radon risk as an environmental hazard

Carlo et al. (1992) evaluated scientists' perception of radon in the context of environmental hazards in the case when the substance was described but not named, as compared to the case when the substance (radon) was named:

Q: "Is [the substance mentioned in the vignette / radon] an environmental hazard?"

Q: "Does [the substance mentioned in the vignette / radon] pose a serious environmental health hazard?"

Q: "Does the substance mentioned in the vignette / radon, background exposure require public health intervention?"

Q: "Does the substance mentioned in the vignette / radon above-background exposure require public health intervention?"

Synergetic risk perception of radon and smoking

In *Hampson et al. (1988)* authors measured peoples radon- and smoking risk perception and a combination of both on a seven-step scale:

Q: The risk is..

- Familiar risk vs. unfamiliar
- Effect on health is quick vs. slow
- I cannot control risk vs. can
- Not frightening vs. frightening
- I know risks well vs. not at all
- Personal choice vs. no choice
- Kills one at a time vs. many
- Risks known to science vs. not
- Old risk vs. new risk.

Rinker et al. (2013) asked respondents to:

Q: Rate the risk of smoking and radon combined compared to the risk of smoking alone: 1 = much less risky; … ; 5 = much more risky

Butler et al. (2017) asked respondent to:

Q: "rate the risk of developing lung cancer from being exposed to radon and smoking a pack of cigarettes per day, compared to the risk of only smoking a pack of cigarettes per day with no radon exposure."

This was measured on a 5-point Likert-type scale

Point of thought: The question wording above is somehow ambivalent because the definition of "a pack" may vary.

Perception of NORM as a health and safety risk

Torres et al. (2017) included three questions to measure how concerned participants were about produced water on health:

Q1: "How concerned are you that storing produced water in tanks might have harmful effects on public health and safety in your area?"

Q2: “How concerned are you that failure of equipment used to handle produced water (e.g. pipelines) might have harmful effects on public health and safety in your area?”

Q3: “How concerned are you that transporting produced water by truck might have harmful effects on public health and safety in your area?”

Answering categories; Not at all concerned; slightly concerned; Somewhat concerned; Moderately concerned; Extremely concerned

Torres et al. (2017) included four questions to measure risk perceptions about NORM in water:

Q: “Give the first thought or image that comes to mind when you heard or read «fracking wastewater»“ (open-question)

Q: “Please rank this thought or image based on the scale ranging from -5 (very negative) to +5 (very positive)”

Q: “Give the first thought or image that comes to mind when you heard or read «natural radioactive material»” (open question)

Q: “Please rank this thought or image based on the scale ranging from -5 (very negative) to +5 (very positive)”

Experts’ opinion on rank of risk of different stakeholders

Torres et al. (2017) asked participants that work in the oil field, do rank the risk (low, medium, high) of three groups: General Public; Operators in the oil field; Hauling truck operators, for scenarios:

- Produced water storage tank overflows and reaches a surface water body
- Equipment leakage (e.g. pipelines) reaches a surface water body
- Truck accident spills produced water and reaches a surface water body

4.3.3.5 Acceptability of risk

Acceptability of radon risk

Poortinga et al. (2008) measured acceptability of radon risk:

Q: “On the whole, how acceptable or unacceptable are the risks of radon to you?” :

1 = very unacceptable; … ; 4 = neither acceptable nor unacceptable; … ; 7 = very acceptable

The acceptability scale was dichotomized with scores 1 to 4 being recoded as 0 (“very unacceptable” to “neither acceptable nor unacceptable”) and scores 5 to 7 recoded as 1 (“slightly acceptable” to very acceptable”).

Recall of information

Weinstein et al. (1992c) assessed recall of personalised risk messages using the following categories:

(1) action not needed; (2) test more before taking action; (3) take action to reduce the level.

Acceptance of information

Weinstein et al. (1992c) assessed recall of acceptance of personalised risk messages using the following categories:

1 = decided not to lower the radon level; 2 = will get more tests and then decide what to do;

3 = all three different specified options , 3a “decided to lower the radon level, but haven’t gotten started yet” or 3b) “have taken initial steps to reduce the radon” or 3c) “have already completed some home modifications”

4.3.3.6 Health-related variables

Importance given to radon by family doctors

Sanborn et al. (2019) asked family medicine residents about the:

Q: “Frequency of assessing environmental health exposure from .. [housing or home (among others)] during history taking”

Q: “Frequency of asking patients about clinically relevant sources of exposure [radon] “

Answers to the questions were: Never; Occasionally; Half of the time; Usually; Always

Health priorities

In the study of *Murphy et al. (2019*) respondents rated their most important and emerging environmental and community health priorities: serious problem; somewhat of a problem; not a problem; do not know

They also rated sources and events as: major contributor; minor contributor; not a contributor; do not know

They then answered questions about data availability on their priorities:

Q: Are the data related to your priorities available? (yes; no; not applicable)

Q: Do you have accessed the data related to your priorities? (yes; no; not applicable)

Q: Are the data related to your priorities adequate? (yes; no; not applicable)

Health behaviours

Gleason et al. (2020) used 3 items:

Q: “Getting seasonal influenza shot in the past year” (yes/no)

Q: “Getting screened for colorectal cancer” (yes/no) (+50 years only)

Q: Aerobic exercise (any/none)

In the study by *Zierold and Sears (2015*) information about health was recorded by the following two questions:

Q: “How would you describe your overall health”: Excellent; Very good; Good; Fair; Poor

Q: “I am as healthy as other people I know” (True/False)

In the study by Zierold and Sears (2015) health conditions were also assessed:

Q: “have you ever been told by a doctor or health care provider that you have *thirty health conditions were given*?”: (circle Y if Yes). . .”

Thirty health conditions were given from which respondents could choose.

Self-reported health status

Gleason et al. (2020) measured self-reported health status on a 5-point Likert scale:

Excellent; very good; good; fair; poor

Experience with cancer in the family

Johnson and Luken (1987) asked whether households contained a member who has recently become a cancer patient.

Contact with health provider

In the study by *Zierold and Sears (2015*) respondents were asked the following question:

Q: "Has a doctor or health care provider ever asked if you lived near an environmental hazard" (Yes/No)

4.3.3.7 Trust in perceived competences

Competences of authorities managing radon risk

In study of *Murphy et al. (2019*) respondents answered 3 questions about the state's EPHT database:

Q: whether they were familiar with it

Q: whether they had accessed it

Q: on the usefulness of the data for their purposes (open-ended question)

Q: rate components of agency's capacity: adequate; somewhat adequate; not adequate; do not know

Trust in state official and oil operators

Torres et al. (2017) asked people to indicate the degree of trust in the following organizations either directly or indirectly involved in produced water management: Oil operators, Truck companies, State/local, Federal government, Environmental Protection Agency

For every organization they had to indicate how much trust they have:

no trust at all; little trust; quite a bit of trust; a lot of trust

Competence of state official and oil operators

Torres et al. (2017) included a question to measure the perceived competence of state agencies:

Q: "How confident are you that the state agencies (e.g. Department of Health and Department of Mineral Resources) will provide honest and accurate information about the safety of produced water handling and disposal?": Not at all confident; Not too confident; Somewhat confident; Very confident; Other

4.3.3.8 Emotions

Emotional response to radon

Emotional responses to radon are broader than concerns (see risk perceptions section) and have been investigated in a number of articles.

In *Sandman et al. (1987)* and *Weinstein and Sandman (1992a,b)* respondents were asked to rate themselves on six adjectives reflecting negative emotions: concerned, depressed, angry, frightened, helpless, and worried.

Q: "When I think about radon, I feel ...": Concerned, Worried, Frightened, Angry, Helpless

Answers were given on a scales: 1= not at all…(e.g. concerned); … ; 5= extremely (e.g. concerned)

In *Weinstein et al. (1989)* the questions about emotion were repeated, with a small modification: a measure for depression was added.

In the article by *Weinstein et al. (1989)* the radon risk emotions were measured by:

Q: “I feel that the radon problem in my home…”

In addition, the article by *Weinstein et al. (1989*) measured Six 5-point scales the amount of concern: worry, fear, depression, helplessness, and anger experienced (e.g., 1 = not at, all concerned, 2 = slightly concerned, 3 = moderately concerned, 4 = very, concerned, 5 = extremely concerned).

4.3.3.9 Communication/engagement variables

Talking about radon

Peterson and Howland (1996):

Q: With whom have you discussed radon or radon testing? Relative; Friend; Co-worker; Physician; Neighbour

Sanborn et al. (2019) asked family medicine residents about sources of exposure that they would discuss with potential parents, among others radon (Yes/No).

Sources of information about radon

Cronin et al. (2020) enquired about sources of radon related information:

TV commercial; Radio commercial; TV news; Radio news; Newspaper/magazine; Internet; Doctor; Family/friend; Realtor; Other

Neri et al. (2018) included following sources:

TV; Family/friend/neighbour/co-worker; Real-estate agent; Home inspector; Contractor (home repair/remodelling); Professional radon testing company; Other

Peterson and Howland (1996) used the following sources for a survey among Boston university employees:

Q: “Through which of the following sources have you received information about radon?”:

Newspaper; Magazine; Radio; Television; Poster; Presentation; Friend/Co-worker/Relative; Boston University Radon Testing Service

Torres et al. (2017) which investigated NORM included a question about sources of information in general:

Q: What is the main source you use to get the latest news?:

Television; Internet; Print; Radio

Ryan and Kelleher (1998) asked people what their sources of advice were:

Companies; Family; Literature; Media; Consultants; Free Phone; Other Sources

In the same study by Ryan and Kelleher (1998) information source was measured through the questions:

Q: "Talked with neighbours?":

Yes, many times; Yes, a few times; Felt they were uninterested; Preferred not to

Evans et al. (2015) asked a more general question in a study addressing, among others, radon risk, namely whether respondents "preferred to receive information about ionising radiation".

Trust in radon information sources

Evans et al. (2015) used a question to ask which source(s) were most trusted to provide information about ionising radiation.

Poortinga et al. (2008) measured trust in authorities as an information source:

Q: I trust the authorities to tell me if my health is at risk from [radon gas].":

1 = strongly disagree; … ; 7 = strongly agree

This scale was also dichotomized. Scores 1 to 4 were recoded as 0 ("strongly disagree" to "neither agree nor disagree") and scores 5 to 7 were recoded as 1 ("slightly agree" to "strongly agree").

Need for information

Smith et al. (1995) assessed the need for information:

Q: "I should know as much as I can about radon because the more I know, the more I can control the risk from radon".

Answers were measured on a 5-Point Likert agreement scale, subsequently dichotomised as 1 for strongly agree or agree, and 0 for else.

Information processing indicators

Johnson and Luken (1987) asked question concerning processing of information from a pamphlet:

Q: How easy it was to understand the pamphlet?

Q: Number of other household members who read the pamphlet

Q: Time spent reading the radon pamphlet

Q: Number of other sources of information that have been sought

Radon information avoidance

Losee et al. (2019) investigated social exclusion, self-affirmation, and health information avoidance. Example of item: "I would rather not know how much radon is in my house":

There were 8 items measured on a 7 point Likert: 1 = strongly disagree; … ; 7 = strongly agree).

Community engagement

Poortinga et al. (2011) used the participation in roll-out involvement for local community involvement as 0/1 variable in their study.

In the study by *Murphy et al. (2019*) respondents were asked how often they engaged with the community through different channels: Weekly; Monthly; Semi-annually; Annually; Never; Do not know

Knowing who to contact to report water spill

Torres et al. (2017) asked people the following question:

Q: Do you know who to contact to report a produced water spill in your area? (yes/no)

4.3.3.10 Measuring/testing for radon

The following section presents the ways researcher inquired about measurement of radiation levels (testing). Findings are summarized in Figure 15.

Measured radon

Sandman et al. (1987) used measured radon level in the basement and measured radon level at groundfloor level.

Losee et al. (2019) asked respondents whether they wished to learn the radon level of homes in their neighbourhood.

Radon testing

Radon testing was typically assessed as in *Cronin et al. (2020):*

Q: "Have you or someone else ever tested your current residence for radon?"

Yes; No; I don't know

Gleason et al. (2020) formulated the question as:

Q: "Has your household air been tested for the presence of radon gas?"

Weinstein et al. (1991) used the following categories to describe the testing stage: never thought about it ; do not plan to test ; thinking about it but haven't decided ; plan to have it done but haven't yet ; test ordered or in progress ; have already received test results

Rinker et al. (2013) dichotomized this scale into those with testing intentions and those without.

Weinstein and Sandman (1992b) used only a part of categories by Weinstein et al. (1991) to capture the testing stage: Never thought about it; Not needed; Undecided; Plan to test

Weinstein and Lyon (1999) adapted the categories of Weinstein et al. (1991) to better capture the respondent's descision: I have already completed a test, have a test in progress, or have purchased a test; I have never thought about testing my home ; I am undecided about testing ; I've decided I don't want to test ; I've decided I do want to test

Sanborn et al. (2019) adapted these categories as follows: Completed or in progress; Plan to monitor; Haven't decided; Not needed; Never thought about it; Never heard of radon

Poortinga et al. (2011) further elaborated the scale of Weinstein et al. (1991) to better describe the options:

Q: Select a statement that "best describes your thoughts before this interview about testing your home for radon." : I have never thought about testing my home for radon ; I am undecided whether or not to test my home for radon ; I have decided I don't want my home tested for radon ; I have decided I do want my home tested for radon' ; 'I have already completed a test for radon ; I have a test for radon in progress ; I have bought a test for radon ; Don't know

The above study then combined the options "I have already completed a radon test," "I have a test for radon in progress," and "I have bought a test for radon" to reflect participants who had taken the decision to test their home for radon, and compared this to all other answering options.

Earlier studies used less response options and subsequently provide less information.

Halpern and Warner (1994), for instance, used the following categories: Have tested for radon; Plan to test for radon; Neither have tested nor plan to test

Weinstein et al. (1991) used the categories: not needed; undecided; plan to test

Weinstein et al. (1991) inquired about the Likelihood of their testing in the next year:

1 = definitely will not test; … ; 5 = definitely will test

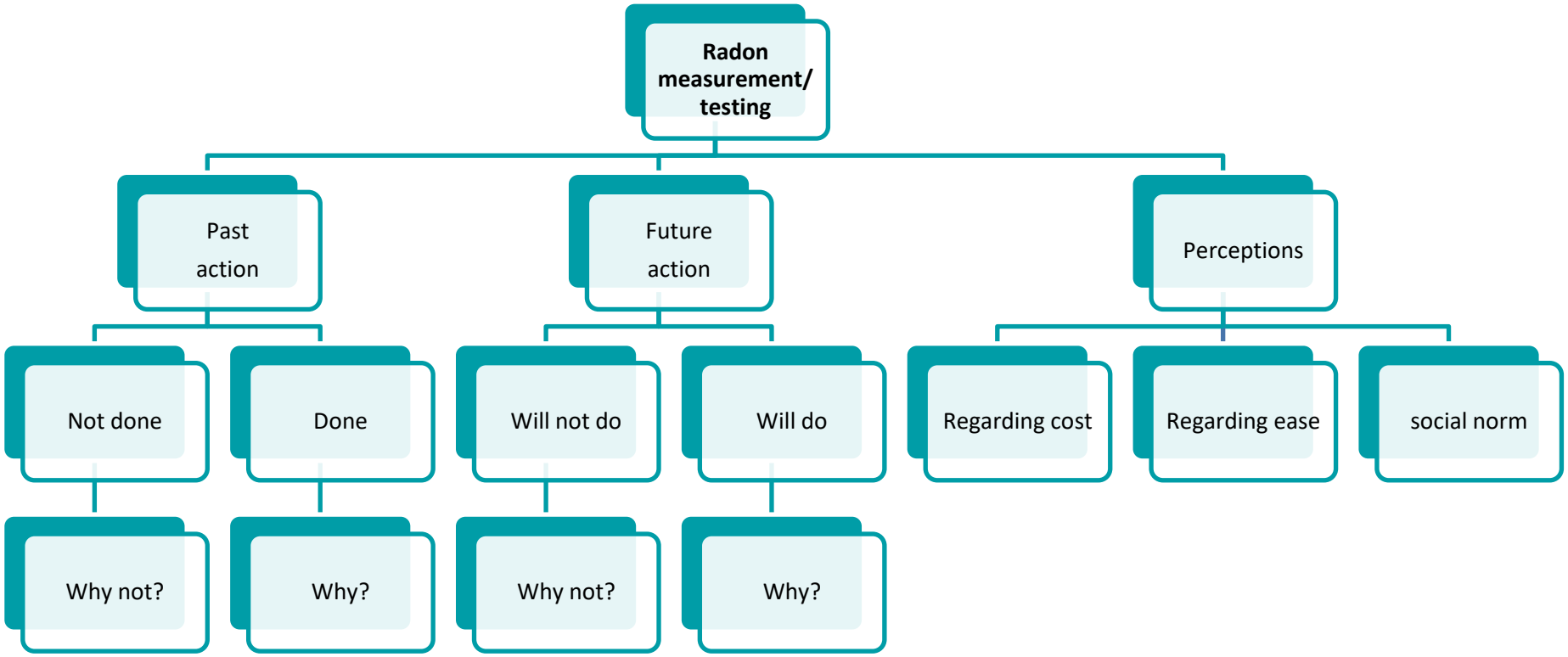

Figure 15 Radon/NORM testing: systematic overview of the variables

Peterson and Howland (1996) assessed the likelihood of several testing actions for non-testers:

Q: How likely it is that you will take the following actions:

- call or write the US EPA to get information on radon?
- call or write to Boston University Testing Service to get more information on radon?
- use a radon testing kit bought from a department store to test your home for radon?
- use a testing kit bought from the Boston university Radon Testing Service

Answers were given on a Likert scale: very likely, somewhat likely, ….

Johnson and Luken (1987) asked whether the respondents have requested household testing, to control for the likelihood that some respondents may wait longer than others to mitigate because of cautious attitudes.

Clifford et al. (2012) probed positive and negative beliefs about the behaviour and behaviour's consequences, e.g. 'radon testing in my house would be useful' (scale not communicated).

Desvousges et al. (1992) used 3 items to measure attitudes towards testing.

Q: "It is important to test my home to find out if I have a radon problem."

Q: "If I had a radon problem, it would be costly to fix."

Q: "Even if a radon problem was fixed, my home would still be worth a lot less."

Likert agreement scale (not specified) + "I don't know" answering category

Perceived ease/difficulty of radon testing

Clifford et al. (2012) used the item "Getting radon tested in my house is easy" as a measure of perceived behavioral control.

In *Hahn et al. (2019),* ease of action, e.g. the item "I can easily test" is included as part of self-efficacy.

Reasons for testing/ not testing

Cronin et al. (2020) used the following categories for evaluating the reasons for not testing:

Don't know how to test; I don't own my own home; Don't believe radon is a health threat ; Too expensive to test; Already have a pump; Other

Clifford et al. (2012) identified the factors influencing not-testing for radon:

their home did not have a problem; did not get around to doing it; were not aware of high radon levels in the area; living in area with boggy soil type; knowing about a case of home with high radon concentration; cost of remediation; cost of testing (least important); could not decide what to do; probable devaluation of their property; waited to see what others will do.

Peterson and Howland (1996) identified the following as reasons for testing the home for radon:

concern about health effects of radon; purchase or selling their home; close friend or relative suggested the test

In mixed-method study by *Ryan and Kelleher (1998*) the following categories were used:

Radon test not that high; Had other radon tests that found lower levels; Did not think there are any steps which can reduce level; Could not find a contractor to perform work; Could not decide what to do; Think risk is exaggerated; Could not get questions answered; Too expensive; Waiting to see what other people do; Just never got around to it; Did not expect to stay in the house very long; Other

Peterson and Howland (1996) formed an index using 11 items:

Q: “I have so many things on my mind that I can’t worry about radon right now”

Q: “If I had a radon problem it would be costly to fix it”

Q: “Even if a radon problem was fixed, my home would still be worth a lot less”

Q: “I do not know how to test my home for radon”

Q: “I do not know where to buy a radon testing kit”

Q: “If I did buy a radon testing kit, I might make a mistake when testing my home for radon”

Q: “The results of radon tests are not reliable”

Q: “I don’t want to get my home tested for radon because I think the results are available to the public (or the state)”

Q: “I don’t have time to test my home for radon”

Q: “If I did test my home for radon and the test revealed unacceptable levels of radon I would not know” how to find an experienced radon contractor to fix the problem”

Q: “I don’t trust the companies that go to homes to test for radon”

Answers were measured on a 5-point Likert scale: strongly agree; agree; neither agree, nor disagree; disagree; strongly disagree

Sources for radon testing recommendations

Neri et al. (2018) asked respondents “who first recommended radon testing”:

Sellers tested prior to purchase; Myself/family member/friend; Real estate agent; Home inspector; Radon professional (other than home inspector); Other

Subjective norm

Clifford et al. (2012) have measured subjective norms relative to radon testing with items such as:

Q: “People who are important to me would like me to get my house tested for radon"

However, the study does not provide all items used.

Knowing other people who tested for radon

Peterson and Howland (1996) asked respondents whether they “knew another person who tested” for radon (Yes/No).

Weinstein et al. (1991) and Rinker et al (2013) asked about the number of people respondents knew, who tested for radon:

Q: “How many people do you know who have tested for radon?": None; one or two people; more than two people.

Attitudes towards radon testing in schools

Martin et al. (2020) asked parents four questions regarding radon in schools:

Q: "I believe that my child's/children's school(s) should be tested for radon levels"

Q: "I believe that my child's children's school(s) should take action to address radon levels it they are elevated."

Q:" I would support a law requiring testing and disclosure of the results of radon levels in schools."

Q: "I would support a law requiring schools to reduce radon levels if they are elevated."

The answering categories used were: Agree, Somewhat agree, Neutral, Somewhat disagree, Disagree.

4.3.3.11 Remediation/mitigation of exposure

Besides testing, remediation/mitigation are the most common behaviours investigated in the field of radon and NORM. First, remediation/mitigation items are presented. These are then summarized in Figure 16.

Radon mitigation response / practice

Cronin et al. (2020) measured mitigation practice with two filter questions and one item:

Filter Q: Have you or someone else ever tested your current residence for radon?: yes; no; I don't know

Filter Q: If, yes [for testing], was the level found to be higher than recommended?: yes; no; I don't know

Q: If yes, was a radon pump installed in your residence?: yes; no; I don't know

In the study by *Johnson and Luken (1987*), among those reporting that they did something to mitigate against radon exposure, many homeowners reported that they undertook simple, low-cost measures such as opening windows more frequently and avoiding basement areas.

Q: Did you do something to mitigate against radon exposure?: yes (if so, which?); no

Smith et al. (1995) investigated the application of a series of radon risk mitigation actions:

1. Increase ventilation: natural (e.g. open windows); installed forced ventilation; heat recovery ventilation; air-to-air exchanger

2. Seal cracks in basement: Install air suction; drain pipe; wall; sub-slab

3. Cover exposed earth

4. Adjust use of house

5. Stop smoking

Perceived ease/difficulty of mitigation

Weinstein et al. (1990) and *Weinstein and Sandman (1992b)* assessed ease of mitigation:

Q: "If people have a home radon problem, do you think it is hard to reduce the radon to a safe level?":

1 = very difficult; … ; 4 = very easy

In *Weinstein et al. (1991)* the question was slightly reformulated, but the same answering categories as above are used:

Q: “How hard it is to reduce radon to a safe level in homes that have problems?”

Remediation concern

In the study by *Feldman and Hanahan (1996)* people were asked to rate commonly cited remediation concerns:

Q: Rate the concerns: 1) risk to human health, 2) environmental risks, 3) risks to plants and animals, 4) surface water and groundwater contamination, 5) the effect of site remediation on local community image, 6) the effect on property values, 7) any future land-use restrictions, 8) the transportation of contaminated soils, and 9) any remediation costs

Answering categories: 1 = little or no concern; .. ; 5 = very concerned

Radon mitigation intentions

Losee et al. (2019) measured radon mitigation intention as likelihood to repair:

Q: “If your house had high radon levels, how likely is it that you would get it fixed?”:

1 = very unlikely; .. ; 10 = very likely

Peterson and Howland (1996) assessed the likelihood of several mitigation actions for non-testers:

Q: “How likely it is that you will take the following actions”:

Seal cracks in the basement or below grade foundation of you have a high level of radon?,

Hire an experienced contractor to fix the problem if you have high levels of radon in your home?

Answers were given on a Likert scale: very likely, somewhat likely, ….

Weinstein and Sandman (1992a) assessed radon mitigation behaviour using the following answering categories:

Already carried out home mitigation (one to 5 months after confirmatory testing); Planned to act but have not yet done so; Undecided; Not needed

Weinstein et al. (1989) measured thoughts concerning future mitigation actions as a function of basement radon level, with the following answering categories: plan to act; undecided; not needed

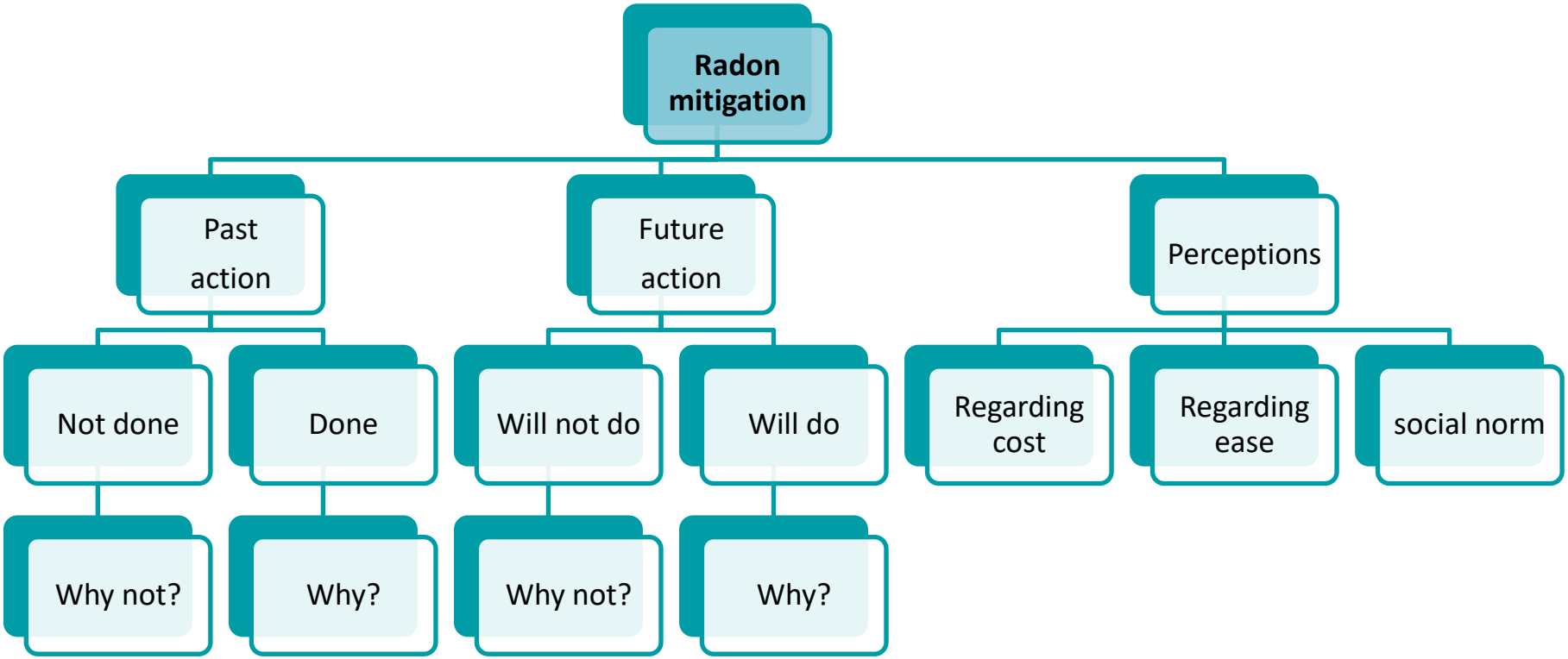

Figure 16 Radon/NORM mitigation: systematic overview of the variables

Perceived benefits and efficacy of remediation measures

Weinstein et al. (1991) used the following variables:

Q: "Does reducing radon levels reduce the chances of getting sick?":

1 = would not reduce the risk; … ; 4 = would reduce the risk completely

Weinstein and Sandman (1992b) assessed on a 4-point scale the Success of mitigation methods and the Risk reduction from lowering level.

*Peterson and Howland (*1996) assessed perceived efficacy or remediation actions:

Q: "If you had a high level of radon, sealing cracks in the basement of below grade foundation is a good way to control a radon problem?":

Q: "If you had high levels of radon, hiring an experienced radon contractor to fix the problem is a good way to control a radon problem?":

strongly agree; agree; neither agree, nor disagree; disagree; strongly disagree

Perception of remediation

Weinstein and Sandman (1987) used 4 items (treated as independent items) to assess respondents' perception of remediation. These items related to:

Q: Experts understand how to reduce

Q: How hard it is to reduce radon levels

Q: Are radon reduction methods successful?

Q: Cost estimate

Financial resources – ability to afford repairs

In *Losee et al. (2019)* participants indicated whether they:

Q: "could afford to repair their homes if their homes had high levels of radon?"

Answers were measured on a 10 point Likert: 1 = Definitely Not; … ; 10 = Absolutely

Cost of reducing radon in home

In *Losee et al. (2019)* the cost of reducing radon in home was used in a manipulation in experiment) as:

2000 USD (high burden)

200 USD (low burden)

Burger et al. (2000) had the following item measured on a 5-point Likert scale:

Q: Willingness to expend federal funds to remove Radon from homes

4.3.4 Reliability and validity assessments

In this section we will discuss the importance of the reliability and validity assessments and present the variables from the reviewed articles for which the reliability or validity of scales have been assessed.

To help explain the widely documented variation in radon protective behaviours, researchers often use psychological constructs. Furthermore, it is commonly assumed that variables such as the 'awareness/severity of radon risks', the 'willingness to test for radon' or the willingness to take mitigating actions' are characteristics on which the individual respondents vary. A central task of work package 6 of the RadoNorm project is to explain and reduce such variation. In practice, however, the adequate quantification of the individual variation on such variables is not an easy task. Measurement issues are obviously not unique to the social and human sciences but here they are undeniably more challenging. Measuring the length of an individual is easier than measuring individual's radon risk awareness, not in the least because radon risks not only vary individually but also in terms of the different locations where those individuals tend to reside (home dwelling, work/school place). In sum, depending on the measurement procedure used, one may assign totally different measurement values to the same research elements. It is therefore very useful to critically reflect on how radon and NORM variables are actually measured. In this section we will specifically discuss the validity and reliability of the quantitative measures used in the studies in our systematic review.

Only when one has clearly defined what one wants to measure, one can start the search for adequate measuring instruments or indicators. Valid indicators actually measure what the researchers want to measure. In other words, validity is a matter of finding suitable empirical representative(s) for a theoretical concept. Validity therefore implies a strong overlap between the conceptual definition and the meaning of the indicator. Yet, it is somehow characteristic for the preliminary state of the empirical social research regarding the assessment and the remediation risks of radon and NORM risks that almost no studies explicitly discuss the validity of their indicators. Yet, as previously mentioned it is far from obvious to measure one's awareness of radon risks. Even among social scientists, there is no unambiguous definition for a notion such as 'awareness'.

For one, it is fairly well known that personal risks are generally perceived to be lower than societal risks. Obviously, it remains to be seen whether there is also such a difference for radon/NORM risks, but in anticipation of clear findings in this regard, it seems best to take the distinction into account. That is why it is best to start by carefully defining what and where (for which location) one wants to measure. Most quantitative studies involved in the systematic review focus on the risks, testing, and remediation of the home of the respondent, but generally it is not specified whether both homeowners and tenants are involved. Only two of the studies (Jones et al., 2019; Martin et al., 2020), inventoried in Table 5, focus on the 'school context' and remarkably none of them focuses on the workplace. In sum, we detect some ambivalence at the level of the conceptualization because the studies reviewed often do not concretely specify the referent of the radon risk, whether it is personal or societal: *Are you aware of the health risks associated with exposure to radon* (e.g. Denu et al., 2019), and often they do not specify the location involved. Furthermore, some studies even use measures that do not specify that they are interested in health risks and just ask 'Have you (ever) heard about radon' (e.g. Eheman, Ford, Garbe, & Staehling, 1996; Ford & Eheman, 1997; Hazar et al., 2014).

Another issue is whether one is interested in actual 'objective' knowledge (revealed) or subjective awareness that cannot be verified. Especially In the latter case social desirability issues may arise, because highly educated respondents are often inclined to overestimate their actual 'technological' knowledge. Some of them might therefore say they have heard about radon, even though this is not really the case. However, also in the quantification of actual knowledge there are some potential problems involved because many people may go for the easy option and will choose 'do not know' if available. Almost all of the studies that are interested in objective knowledge use a relative measure in comparison with some kind of benchmark. This seems the appropriate approach to take because

absolute questions such as '*do you think radon may be present in your home?'* are of course highly ambiguous (e.g. Khan et al., 2018). Often the researchers compare the risk of radon exposure to that of smoking. Interestingly, some studies do not specify the smoking intensity (e.g. Hampson, Andrews, Barckley, et al., 2000; Khan et al., 2018), but most studies refer to smoking a packet of cigarettes per day. Whether a specific conceptualization is better than another, of course, to some extent depends on the concrete purposes of the study. But research that combines the risks of smoking and of radon exposure in a single item (e.g. Hampson, Andrews, Lee, Lichtenstein, & Barckley, 2000) are not very useful for radon research. In practice it is therefore not desirable to separate the conceptualization phase from the measurement phase. In this respect it is remarkable that so many studies do not specify the actual measures they used (Hazar et al., 2014; Keller, 2011; Kennedy et al., 1991; Larsson, 2015; Prochaska et al., 1994).

Although the assessment of behaviour such as performing a radon test or taking mitigating actions to reduce the health risks involved seems easier than assessing awareness, some conceptual issues cannot be avoided. Some studies do not specify whether the testing/mitigation relates to the current place of residence. A measure such as '*have you ever tested your home for radon'* may not refer to the current place of residence. Furthermore, some studies do not measure past behaviour but rather future planned behaviour. Behavioural intentions are obviously less reliable, especially if the involved costs of action are not specified. Interestingly, only one study measured conditional behavioural intention, e.g. '*how likely would you be to spend $1000 in order to reduce level of asbestos or radon close to zero'* (Sandman, Weinstein, & Miller, 1994). Yet, some studies indirectly measure those conditions by explicitly registering the reasons why someone did not test/ did not take mitigating actions (see Dowdall et al., 2016; Riesenfeld et al., 2007).

It is also interesting to give some attention to the operationalization of the indicators, for example with respect to the number of answering categories and the way they are worded. Attitude or awareness items are typically measured based on a Likert response format with five categories: agree completely, agree, neither agree nor disagree, disagree and completely disagree. This is associated with the name of Likert, who popularized it. Typical about the Likert-answering format is that the uneven number of answering categories allows for a neutral middle category which is appropriate if many respondents do not have fully crystallized opinions. Most of the studies stick to the 5-point answering format which is good for comparative purposes. Nevertheless, three studies (Dragojevic et al., 2014; Hahn et al., 2019; Hampson, Andrews, Lee, et al., 2000) use a 9-point answering format which might be a little too sophisticated because measurement studies have established that most respondents are only able to take seven categories into account.

However, in terms of psychometric qualities the number of categories is far less important than the number of indicators used. It has become well accepted that the differences on a rather complex concept such as risk awareness cannot adequately be measured by means of one single indicator. For one, each measure is exposed to measurement error. First, if one uses several items, one can somehow neutralize the measurement error that is unique to one (or only some) indicators. Second, to clearly identify the different positions an individual can take in on a certain concept one needs easier as well as more difficult items. Last but not least, by assuming that all of the indicators measure the same underlying latent construct one can test the validity and the reliability of the measurement instrument. In order to properly test those psychometric qualities, one needs a scale composed of at least three indicators. For a two-item scale one must rely on the correlation as a suboptimal indicator for both validity and reliability. Paradoxically, 60 out of about 100 quantitative measures involved in the studies of our systematic review are single indicators. While this may be less of a problem when testing behaviour is involved, often these single indicators are also used to measure complex multidimensional constructs.

By carefully evaluating the overlap between indicator and concept in the preceding discussion we gained some insight in the 'face validity' of the different measures used in the existing radon/NORM studies. Furthermore, we obtained an idea about the 'congruent validity' of the measures by comparing them.

However, a critical finding of this review is that attention to validity issues is almost absent in the radon/NORM papers themselves, not in the least because of the dominance of single indicators. Furthermore, even in the handful of studies that do use measurement scales validity is hardly systematically discussed. If factor analysis is used the (standardized) factor loadings may nonetheless provide useful information on the validity of an indicator. Only the study by Perko, Zeleznik, Turcanu, and Thijssen (2012) provides such information for a scale composed of more than two items.

This gap in the social research literature in the field of radon and NORM is related to the fact that these tend to focus on one measurement instrument at a time. Until now, no measurement models have been applied which simultaneously look at several interrelated measures. radon/NORM research typically assumes that measurement instruments are unidimensional, although this is often not tested because of the use of single indicators. However, in nearly all of the studies that do use scales one looks at the reliability, notably the internal consistency. The basis assumption behind internal consistency is that to the extent that the different indicators of the scale measure one and the same concept, there must of course be a high degree of coherence between the answers to these indicators. The starting point is that people who are 'equally' aware of radon health risks should react in a similar way to the various awareness indicators. This interpersonal internal consistency is typically evaluated with the Cronbach's alpha. 11 studies report Cronbach alpha's that are almost without exception satisfactory (> .70) (Dragojevic et al., 2014; Hahn et al., 2019; Hampson, Andrews, Barckley, et al., 2000; Hampson, Andrews, Lee, et al., 2000; Larsson, 2015; Mazur & Hall, 1990; Perko, 2014; Perko et al., 2012; Prochaska et al., 1994; Sandman et al., 1994; Weinstein et al., 1998). Yet, unfortunately we see almost no cross references with respect to the question wording. Overall, most scales are rather synergistic and idiosyncratic, in the sense that they bring together multiple risk assessments in a rather ad hoc way.

One can also evaluate reliability over time. If one uses the same indicator(s) at different moments in time, one should, ceteris paribus ('all other things being equal'), also see a fairly large coherence between the answers. This is called intertemporal or test-retest reliability. None of the studies uses such a measure which is indicative of the fact that most studies are of a cross-sectional nature. Panel studies that evaluate awareness of the same individuals at different moments in time is hitherto absent, while such studies are nevertheless crucial to evaluate the success of government interventions and information campaigns. Some studies retrospectively evaluate the intensity of people's interpersonal communication about radon (Coleman, 1993; Park, Scherer, & Glynn, 2001) and which information channels (Hazar et al., 2014; Kennedy et al., 1991; Mazur & Hall, 1990) they use to get informed about radon, but obviously in order to properly evaluate information effects one should have valid and reliable measures of awareness before and after the information was communicated.

Table 5 - Overview of the reviewed articles where reliability of the scales was assessed

				Reliability		Validity		
Study	**Construct**	**Items**	**Response options**	**Internal consistency**	**Test-retest**	**Factorial**	**Construct**	***Question/ Comments***
(Dragojevic et al., 2014)	Radon severity	4	9 point Likert-type	α = .90	NR	NR	NR	*e.g. Q "Radon gas is a serious threat to health"*
(Dragojevic et al., 2014)	Radon susceptibility	3	9 point Likert-type	α = .80	NR	NR	NR	*e.g. Q "I am at risk for exposure to radon gas"*
(Dragojevic et al., 2014)	Response efficacy	4	9 point Likert-type	α = .88	NR	NR	NR	*e.g., Q: "The recommendations presented in the article are effective"*
(Dragojevic et al., 2014)	Self-efficacy	4	9 point Likert-type	α = .93	NR	NR	NR	*e.g., Q "I am able to do what is needed to prevent radon gas from harming me"*
(Dragojevic et al., 2014)	Behavioural intention	4	9 point Likert-type	α = .73	NR	NR	NR	*e.g. Q "How likely is that you will have your current residence tested for radon gas?"*
(Dragojevic et al., 2014)	Fear arousal	4	9 point Likert-type	α = .84	NR	NR	NR	*e.g. Q "The article made me fearful"*
(Hahn et al., 2019)	Self-efficacy: radon test	3	5 point scale	α > .83	NR	NR	NR	*Q Ability (e.g., "I am able to test my home for radon to prevent lung cancer"), resources ("e.g., I have the time to test"), and ease of action (e.g., "I can easily test")*
(Hahn et al., 2019)	Self-efficacy: radon mitigation	3	5 point scale	α > .83	NR	NR	NR	*Q Ability, resources, and ease of action*
(Hampson, Andrews,	Synergistic risk with smoking	4	9 point scale	α = .88	NR	NR	NR	*Q: "How likely is that radon and smoking in your home will seriously damage your health?" "How likely is that radon and smoking in your home*

Barckley, et al., 2000)								*ill seriously dam age the health of other household members?" "How likely is that radon and smoking seriously damages the health of people in general?" and "Compared to all the other things that can damage your health, is the risk of radon and cigarette smoking something you can think about calmly or is it one that you find frightening?"*
(Hampson, Andrews, Lee, et al., 2000)	Radon risk perception	5	9 point scale	α = .90	NR	NR	NR	*Q 1: "How likely is it that radon in your home will seriously damage your health?'* *Q2: "How likely is it that radon in your* *home will seriously damage the health of other household members?"* *Question 3: "How likely is it that radon in their homes seriously damages the health of people in general?"* *Question 4: "Compared to all the other things that can damage your health, are the risks of radon something that you* *can think about calmly or is it one [sic] that you find frightening?"*

								Question 5: "Compared to all the other things that can damage your health, *to what extent do you feel you know about the risks of radon?"*
(Hampson, Andrews, Lee, et al., 2000)	Radon and smoking risk perception	5	9 point scale	α = .88	NR	NR	NR	*Q 1: "How likely is it that radon and smoking in your home will seriously damage your health?'* *Q2: "How likely is it that radon and smoking in your* *home will seriously damage the health of other household members?"* *Question 3: "How likely is it that radon and smoking in their homes seriously damages the health of people in general?"* *Question 4: "Compared to all the other things that can damage your health, are the risks of radon and smoking something that you can think about calmly or is it one [sic] that you find frightening?"* *Question 5: "Compared to all the other things that can damage your health, to what extent do you feel you know about the risks of radon and smoking?"*
(Larsson, 2015)	Rick perception	8	7 point scale	α = .81	NR	NR	NR	

(Larsson, 2015)	Self-efficacy	7	0-100	α = .71	NR	NR	NR	
Losee et al. (2019)	Perceived financial burden	2	10 point scale	α =.8	NR	NR	NR	*Reducing radon would be burdensome for me* *Reducing radon in my* *house would require more resources than I have*
(Mazur & Hall, 1990)	Seek information on home radon reading	2	3 points	gamma=.74	NR	NR	NR	*Q1asks if they discussed the readings with anyone in an effort to better* *understand whether a health risk existed; Q2 asks if they discussed with anyone how to reduce radon levels in their homes.*
(Mazur & Hall, 1990)	Radon concerns (home)	2	3 points	gamma=.81	NR	NR	NR	*How much of a problem is the* *radon level in your home?* *If you don't take any action, do you think the radon in your home will eventually make you sick?*
(Mazur & Hall, 1990)	Radon concerns (general)	3	3 points	gammas ranged from .48 - .90	NR	NR	NR	
(Perko, 2014)	Risk perception-Radon	1	5 point scale	.56 for 2 item scale comprising "natural radiation"	NR	.71 load onto F2 (with medical X ray)	NR	*"evaluate the risks for an ordinary citizen of Belgium" for the following radiation risks: natural radiation (e.g. cosmic radiation or radon) + 3 other items*

				and “medical X-ray)				*Factor structure was not invariant across samples – general population (1 factor) vs. experts (2 factors)*
(Perko et al., 2012)	Risk perception – radon	1	5 point scale	.81 for 4 item scale	NR	.61 load onto radiation risk factor	NR	*“evaluate the risks for an ordinary citizen of Belgium” for the following radiation risks: natural radiation (e.g. cosmic radiation or radon). + 3 other items*
(Perko et al., 2012)	Risk perception – radon	1	5 point scale	.67 for 5 item scale	NR	.55 load onto radiation risk factor		*Slovenia were asked to evaluate* *five different radiation risks:* *radon in house + 4 others*
(Prochaska et al., 1994)	Decisional balance	8	5 point scale	Pros:α =.94 Cons:α=.87		2 factors No details on item loadings	NR	
(Riesenfeld et al., 2007)	Radon knowledge	3	Response options vary 3 for q1-2 8 for q3 Can tick more than one response for q1 and q3	NA	NR	NR	NR	*What is radon?* *Belief that radon is a health hazard* *If radon is a health hazard which of the following is caused by exposure to radon: 8 options*

(Sandman et al., 1994)	Perceived threat	4	5 point	α=.84				*perceived likelihood of developing some illness from this level of exposure; perceived danger of this level* *; expected concern from finding such a level in one's home; and expected fear*
(Weinstein et al., 1998)	Radon risk perception	3	5 options	α = .83	NR	NR	NR	*perceived likelihood in own home, percentage chance in own home, and percentage prevalence in community*
(Weinstein et al., 1998)	Perceived ease of testing	2	5 options	α = .62	NR	NR	NR	*Ease of finding a test kit; ease of using a test kit:*
Weinstein et al. (1992c)	Satisfaction with information	5	2 question 3 options, 3 questions 4 options	α =.86	NR	NR	NR	*Whether the test results had been explained clearly* *Whether the action recommendation had been clear* *Whether DEP (Department of environmental Protection) information is trustworthy* *Whether additional information could be obtained from DEP if needed* *How the DEP program should be rated*

4.3.5 Reflections and recommendations

The vast majority of the reviewed articles employed a quantitative research design which allows for generalization of research findings from the sample to the population at large. However, as shown through the reviewed articles, this extension is not absolute. Only 19 authors claimed generalizability. This result can partially be attributed to the common use of non-probability techniques in the articles under review. Participants were often chosen by the judgment of the researcher (purposive sampling) or because of their willingness to participate, and convenient presence (convenience sampling). Conclusions are thus subject to bias. If researchers wish to avoid biased observations, the target population and sampling strategy needs to be carefully chosen. Probability samples have the highest statistical probability to be representative of the population since every individual has an equal chance of being chosen. It is equally important for researchers to clearly describe the sampling strategy, size and composition, since readers and reviewers use this information to determine the accuracy of the results. One of the challenges in this review was to determine which sampling strategy was used, since well-established terminology was not – or wrongfully - used in many articles. This terminology includes: simple random sampling, stratified random sampling, cluster sampling, systematic sampling, convenience sampling, purposive sampling, quota sampling and snowball sampling.

To recruit these participants, a variety of modes have been used. Traditional modes such as letter, telephone and face-to-face recruitment were used most prevalently. However, the distinction between “letter” and “email” was not always clear due to the use of the term “mail”, which could refer to either. In some articles a multi-mode approach was used, which possibly could have improved response rates, although this was not evaluated in this review.

A widely recognized method to minimize nonresponse is Dillman’s (2014) Tailored Design Method. Researchers can improve response to internet, phone, mail, and mixed-mode surveys by increasing benefits and trust and decreasing costs for participants. Among other things, researchers should inform and show appreciation to participants and make questionnaires as interesting, short and easy as possible (Dillman et al., 2014). It is also important that they assess and report on non-response to uncover response bias.

The review of quantitative studies conducted on societal aspects of radon and NORM highlighted that very few studies conduct and report reliability and validity considerations.

In the reviewed articles it was not always clear which construct was investigated, for example whether it was “awareness” or “knowledge”. This shows that it is important to first provide clear operational definitions of all constructs of interest.

The literature can then be searched for pre-validated instruments that can be used directly or in a modified form. However, if such modifications are performed or if the instrument is presented to a different population, the consistency and accuracy of the instrument(s) need to be assessed again. The reason for this being that reliability and validity are products of the data and the context. Contextual information should also be reflected in the items.

In general, considerably more studies focus on radon risk perception, knowledge of radon and perceived susceptibility, as potential predictors for radon testing and mitigation. Other psychometric constructs such as subjective norms or perceived behavioural control, and concepts such personal or community engagement are less studied, despite their proven influence both in what concerns radon testing and mitigation, as well as in broader contexts pertaining to the adoption of health behaviours.

It is thus important to assess attitudes and behaviours from a holistic viewpoint, in terms of health, as well as technical, economic and social considerations. In terms of behaviour it is also important to inquire both reasons for behaving as for not behaving in a certain way.

If researchers cannot find existing instruments to measure what they aim to investigate, they can self-construct instruments. Here it is important that they clearly describe the design: which items will be used, how many items, the order of the items and of course how valid and reliable the measures of the constructs of interest are.

Many constructs in the articles in the review were measured through one item. This insufficiently captures the full breadth of a construct and usually not a reliable measure. In future studies, multiple items should be presented per individual construct.

In some of the studies (particularly frequently among those older than 2010) several items were presented relating to one construct, but these items were then used independently in analyses.

If authors have the intention to build a scale, but the scale does not satisfy reliability requirements, it is important that this is explained.

Furthermore, when several answering categories are presented for one item, it is important to ensure that the list is exhaustive, and categories are mutually exclusive. Including an “other”, “I don’t know” or “I prefer not to say” option, ensures that all possibilities are accounted for. However, the way such missing or deviating values are treated should be reported. Alternation between open and closed questions can also aid in capturing the range of answering possibilities.

If researchers seek to uncover potential problems in their research design and/or instruments regarding the reliability, validity and understandability of items, they can conduct a small-scale preliminary study, also known as a pilot study. After successful pilot testing, data can be collected from a larger sample.

In order to improve the methodological quality in future studies, we formulated following recommendations:

Key recommendations for quantitative studies:

- Report sampling strategy, size and composition
- Employ probability sampling techniques
- Minimise, assess and report item and unit non-response to uncover nonresponse bias

Define the construct

- Clear operational definitions of all constructs should be provided.
- Items should reflect the full breadth of the construct being assessed.
- At least 3 items are required for each construct
- Items should include important contextual information (e.g., location of risk; comparators)
- Item response options should be sufficient to be sensitive to discriminate between levels but there should not be too many; we recommend 5 to 7-point scales

Validity

- Comparisons with other similar constructs (congruent validity) or dissimilar constructs (concurrent validity) are useful
- Evidence of validity, e.g. factor loadings of crucial items, needs to be presented to justify interpretation of the construct

Reliability

- Evidence of internal consistency should be presented; this should be calculated for each sample that the scale is used with
- Evidence of intertemporal or test-retest reliability should be provided for intervention or longitudinal studies to ensure that changes in constructs over time are not just measurement error

Socio-demographic background variables

- Use category “other” in gender
- Account for passive smoking in studies on the synergetic effect of radon and smoking
- Home ownership status: use also category “other” besides “owner” or “rented” to account for other situations, such as living with friends at no costs;

Topical variables:

- If knowledge questions are used, provide information to the respondents at the end of the survey to clarify the correct answer to the knowledge questions
- Avoid using perception related concepts (e.g. expensive or inexpensive) in knowledge questions
- Use a detailed description when assessing the radon testing stage and radon mitigation intentions, rather than yes/no variables.
- Enquire about radon test results both in basement and at ground floor level
- Combine open and closed questions to identify reasons for testing / not testing for radon
- Use filter questions when assessing radon mitigation intentions to control for test result being higher than recommended level.

Perceive benefits and concerns related to remediation

- Assess benefits and concerns from a holistic viewpoint, in terms of both health (e.g. reduces health risks), as well as technical (e.g. is it effective), economic (e.g. increasing/decreasing property values or facilitating property sale) and social considerations (e.g. community image).

Information about radon/NORM and trust/competence of risk management actors

- Include also informal sources and specific national and local actors when assessing sources of information and trust in actors for radon / NORM exposure testing and mitigation.

4.4 Qualitative methods

All together 17 articles were analysed which included the performed qualitative research in the area of radon from 1990 on, only one article was identified and analysed where qualitative research in the area of NORM was reported (see Table 6 for overview).

The qualitative investigations were focused on the understanding why the radon health impacts are now perceived as dangerous and real problem as reported by scientific findings and why there are not more intentions for the mitigation actions in the area with higher radon concentrations and on the reasons for communication problems between experts and affected members of the public in NORM risk management. The methods for the investigations included focus groups (N=4) (DiPofi, LaTour, & Henthorne, 2001; B. B. Johnson, 2017; Momin et al., 2018; Witte et al., 1998), interviews (N=5) (Bostrom (Alsop, 2001; Alsop & Watts, 1997; Bostrom, Fischhoff, & Morgan, 1992; Khan & Chreim, 2019; Whittaker, 1988) document analyses of secondary data (N=3) (Cothern, 1990; Hamilton, 2003; Macher & Hayward, 1991), observation studies, like pilot study to change risk management by using local authorities (Scivyer, McLaughlin, Simopoulos, & Steinhausler, 2005), comparative studies of attitude and behaviour between two or more groups, and lately also the examination of the impacts of learning experiences on the attitude and perception (a kind of citizen science) (N=4) (Johansson (Groppi, 2018; Immé et al., 2013; Johansson et al., 2007; Pugliese, La Verde, & Roca, 2019). The NORM investigation the interview method was used with guided interviews (König, Drögemüller, Riebe, & Walther, 2014).

Due to diversity of the approached used, it was challenging to perform a synthetic analysis across the articles. Therefore, the overview that follows will present the topics addressed, the methods used, the participants involved in the investigations, the material used and the most important results from the individual papers. The overview follows the timeline of contributions which indicates the development of the qualitative radon and NORM research.

Table 6 - An overview of the qualitative articles

Reference	Topic studied	Methods of sampling, recruitment, data collection	Data analysis	Rigour assessment
(Cothern, 1990)	The potential reasons for the apathy and the public's reaction to information concerning the health effects of indoor air radon concentrations	Sampling: No information Recruitment: N/A Data collection: Secondary data analysis	No information	N/A
(Macher & Hayward, 1991)	Indoor air quality issues about which Californians most often sought advice from a health department or a public information agency.	Sampling: residents that called to California Interagency Working Group (IWG) on Indoor Air Quality Recruitment: N/A Data collection: content analysis of documents	During or soon after a conversation, contacted IWG members recorded the information in a form that a caller volunteered. They categorized callers, buildings, topic of the call, physical symptoms	no inter-rater agreement (or equivalent) is provided Respondent validation – not mentioned No quotes
(Bostrom et al., 1992) *Radon*	Studied lay people's understanding of the physical, chemical, and biological processes and their response to an environmental hazard	Sampling: general public Recruitment: from civic groups, through signs posted at local libraries. Data collection: interviews (N=24) -> mental models, Interviews were performed by single interviewer, lasted approx. 45 min, and contained non-directive (asked to describe everything they know about radon) and directive stage (asked to sort photographs according to if they had anything to do with radon)	The interviews were transcribed, checked by interviewer and coded into the expert influence diagrams.	After reaching agreement on two initial interviews, coders, along with a third researcher, coded two additional interviews independently. All three coders agreed about 75% of the time, depending on the interview and concept category. his seems like reasonably good agreement for such a fine-grained coding scheme. Respondent validation – not mentioned Quotes - no

(Alsop & Watts, 1997) *Radon*	Investigated through a series of cases within informal learning contexts in the UK models of conceptual change learning which beside cognitive domain also encompassed issues of affect, conation, and self-esteem.	Sampling: Local population Recruitment: snowball in local community Data collection: semi-structured interviews (N=4), 1 hour long,	Interviews were tape recorded onto audiocassette and then transcribed in full. No information on analysis	Quotes yes Respondent validation – not mentioned
(Whittaker, 1988) *Radon*	To explore, based on an ethnographic study, one Australian community's popular epidemiology of the role of the environment on health.	Sampling: residents of Oceanpoint Recruitment: purposive through local community groups Data collection: 88 transcribed in-depth open interviews (1 hr) with residents of Oceanpoint and seven focus group discussions	Not described	Quotes yes Respondent validation – not mentioned
(Witte et al., 1998) *Radon*	The focus group protocol included sections: knowledge of radon, radon testing, and radon reduction; perceived severity of radon, perceived susceptibility of harm from radon, perceived response efficacy of testing and reduction, and perceived self-efficacy toward testing and reduction; radon reduction behaviours in which participants might have engaged; reactions toward existing campaign materials in terms of the level of perceived severity or susceptibility and the level of response and self-efficacy they promoted and	Sampling: African Americans Recruitment: at worksites or churches and were eligible for participation if they smoked or had ever smoked or if they had children under age 12 Data collection: 9 focus groups (N=64) Each session was audiotaped and lasted approximately 11/2 to 2 hours.	Standard focus group analytical procedures were followed: transcription of discussion, developed of classification scheme, coding, distribution of coded material discrete tables, and interpretation of the analyses. At least two members of the research team independently examined each transcript and extracted phrases or statements that fit into each category,	The focus group protocol was pretested with researchers (completeness, accuracy, and flow) and with African American homeowners to determine (1) flow of the protocol, (2) timing (e.g., how long does the focus group take?), (3) understandability of the questions (e.g., is the language used appropriate and easy to understand?), (4) problems with content (e.g., are there certain items that people refuse to answer? why?), and (5) introductory procedures (e.g.,

	suggestions from focus group members on what effective campaign materials should address			scripts for introducing the topic and securing cooperation with subjects). No agreement reported Respondent validation – not mentioned Quotes - yes
(Alsop, 2001)	Explores if people living with the immediacy and relevance of higher than average levels radioactivity are more knowledgeable and emotionally detached compared with a similar group removed from this health concern	Sample: 'recent school leavers' in the UK is documented. Data collection: interviews (n = 30) A methodology of Interviews-About-Scenarios (IAS) was used to elicit discussion not only about what conceptual system learners hold, but also how they felt about this knowledge as well. Twenty different scenarios were used and took the form of line drawn pictures, presented on A4 card.	The interviews were transcribed and analysed based on five stages Grounded Theory methodology.	The coding process was completed independently by two researchers. Where there was a disagreement a discussion took place so that either a consensus was reached or adaptation to the category was made. Respondent validation – not mentioned Quotes - yes
(Hamilton, 2003)	Investigates how participants in risk debates draw upon and combine aspects of technical and cultural rationality as broad orientations to risk in expressing their views and formulating persuasive appeals during risk debates	Sample: N/A Recruitment: N/A Data collection: Secondary data analysis A rhetorical analysis is conducted using the transcript from a 1995 public meeting during which local residents and a nuclear medicine expert discussed priorities of Fernald site clean-up versus providing	Rhetorical theorist Kenneth Burke's concept of frames of acceptance is used to analyse a case study involving competing priorities for radium stored at the Fernald site, a former Department of Energy nuclear weapons facility. radium stored on site for promising cancer research. No information provided on the process of analysis	No information

		radium stored on site for promising cancer research.		
(Scivyer et al., 2005) *Radon*	A pilot study funded by UK government to see if local authorities could be used as a focus for raising public awareness and encouraging remediation of radon risk	The pilot studies were organised with 3 local authorities with high prone radon areas with homes with a greater than 5% probability of being above the Action Level. The contacts with householders were established via different approaches: home visits, radon public venues, roadshow events and telephone connections. Methods used: Radon months, media coverage, publicity material, seminars, training events	Observed increase in number of houses measured	N/A
(Johansson et al., 2007) *Radon*	Present radon measurement activities at Stockholm House of Science, which aim to introduce nuclear and experimental physics in a way that attracts the attention and interest of the students. These projects give the students the opportunity to use mobile detectors, either in their school, in the House of Science or in their homes	Participatory approach During 2006, 34 radon experiments were organized for school classes or groups of students. There were 21 shorter activities, ten one-day projects and three projects lasting for one or more weeks		N/A
(DiPofi et al., 2001) *Radon*	Exploratory qualitative analysis to gain in-sight into perceptions of the threat of radon in the Karst geological region in USA.	Sample: local residents Recruitment: with the help of local public health officials Data collection: 5 focus groups (N=50)	No information	No information Quotes- yes

		Focus group outlines were developed to provide contiguity between groups and to explore the facts about the nature of radon awareness and what actions have been taken because of this awareness (both maladaptive and adaptative).		
(Immé et al., 2013) *Radon*	Two programs on scientific dissemination in the field of environmental radioactivity, implemented from 2005 on in Italy. High school students in many Italian regions were involved in particular in indoor radon measurements.	Participatory, high school students In total about 500 detectors were placed in dwellings and schools in 57 locations. With this program students acquired awareness about the risks of inhalation of radon and its progeny and at the same time contributed to carry out radon monitoring, participating to all the experimental phases, from detectors set-up to data analysis. In the end of the year students presented results and reflection on the department meeting, and heled create and populate maps		N/A
(B. B. Johnson, 2017) *Radon*	Investigation on citizen-preferred options (including any not yet suggested by policy makers) for radon mitigations and difficulties in presenting needed background information so that policy preferences are valid and reliable	Recruitment: from customers of utilities that would be affected by the policy choice (i.e., radon levels of 300–4,000 pCi/L). Data collection: 6 Focus groups approx. 10 people each (in total 60),	Focus groups discussions were tape-recorded and transcribed. No information on analysis	Respondent validation – not mentioned No information on coder agreement Quotes - yes

		The group interviews were semi-structured, which means that they used responses from group participants to guide the majority of questions asked, rather than having a fixed set of questions ready beforehand.		
(Groppi, 2018) *Radon*	An experimental activity that involves 1400 secondary school students involved in radon measurements.	Participatory, secondary school children	N/A	N/A
(Momin et al., 2018) *Radon*	To determine radon-related knowledge, attitudes, and practices among Realtors (association with real estate trade members in USA) to inform cancer control activities at local and state levels	Sampling: realtors Data collection: 3 focus groups (5-10 participants) A focus group moderator guide that included open-ended questions on radon was developed, as well as additional probes to stimulate discussion among participants	Authors developed a codebook to code the focus group data to ensure a high level of dependability in the analysis. Similar patterns, codes, and themes were identified, which contributed to the rigor and dependability of analysis. Our approach to coding and analysis was based on currently recommended analytic procedures for focus groups and was an iterative process. Large segments of the data were coded initially by one coder. Over the course of the analysis, codes were reviewed and compared across transcripts to ensure accurate coding. We also limited the number of codes by condensing some of the codes into larger codes, to ensure organization of data for analysis and utility of codes. A	A second analyst reviewed the codebooks and examples of how the codebook was applied to the focus group data to establish interrater agreement. The second analyst did not identify any discrepancies in the coding Respondent validation – not mentioned Quotes – no

			constant comparative method was used, in which the coding strategies and findings were compared across transcripts	
(Khan & Chreim, 2019) *Radon*	Study perceptions of radon health risk and examine the factors that enable and hinder the adoption of preventive measures among Ottawa-Gatineau residents	Sampling: local residents Data collection: Semi-structured interviews (N=35)	All interviews were digitally recorded and then transcribed. "We adopted an inductive approach to the analysis and focused on understanding issues from the perspective of residents. Following Braun and Clarke and Miles et al., after familiarization with the transcripts, initial codes that were close to the data were applied. The first author initially coded seven interviews, using descriptive codes. The process of coding was iterative: as this coding progressed, new codes were added, and some codes were modified. Following this step, the second author reviewed the coded interviews, and the two researchers developed a code list that was used to recode the interviews. The first author then continued coding the other transcripts, while also convening with the second author on a regular basis to discuss emerging patterns in the data. These patterns or themes were developed in answer to the research questions."	Inter-rater agreement – N/A Respondent validation – not mentioned Quotes given

(Pugliese et al., 2019) *Radon*	Investigates the importance of Work-Based Learning experiences of Italian high school students and how some extracurricular basic knowledge may influence the student's intrinsic motivation	The experience of about 120 students of three different schools located in Campania Region (South Italy) were considered. the goal has been to educate students on topics such as environmental radioactivity and in particular about the public exposure to radioactivity of natural origin (cosmic rays, radon…), in the framework of Astroparticles' School of National Institute of Nuclear Physics, also introducing they in real measurement campaigns.		N/A
(König et al., 2014) *NORM*	Explores the underlying reasons for communication problems between experts and affected members of the public.	Sampling: local residents, journalists, experts, people from community gardening area Recruiting: through gatekeeper processes for residents, through professional networks for experts Data collection: qualitative interviews (N= 26)	All interviews were tape-recorded, transcribed and anonymised. Each interview text was then analysed by qualitative content analysis, in which transcripts were extracted, and the extracts were analysed and interpreted in a circular process. In analysing the statements of the residents and the experts according to the qualitative content analysis, different category clusters were used.	Agreement not mentioned Respondent validation – not mentioned Quotes - yes

N/A – not applicable

4.4.1 Topic studies in qualitative articles

Cothern (1990) analyses based on the findings from some US studies the potential reasons for the apathy and the public's reaction to information concerning the health effects of indoor air radon concentrations. Although the risk due to exposure to radon is clear, there is a range of ambiguities and causes that prevent most people from having much concern or acting on that information. This range goes from causes we can do something about to causes over which we have little control. Several reasons for the apathetic reaction concerning radon are discussed starting with scientific illiteracy, characteristics of individuals, environmental problem burnout, input from others and finally human nature.

Macher and Hayward (1991) report on the indoor air quality issues about which Californians most often sought advice from a health department or a public information agency. Members of the California Interagency Working Group (IWG) on Indoor Air Quality kept records of inquiries they received over a 30-month period from mid-1985 through 1987. In total 43 IWG members, representing 12 agencies, completed a standard record form summarizing telephone requests for information, assistance, or advice on matters related to IAQ. Members of the IWG answered calls from residents of a least 49 of California's 58 counties, with annual average of 1491. IWG members received more public inquiries about residences than about offices, educational institutions, commercial buildings, or medical facilities. Homeowners themselves asked the majority of the questions about residences, whereas a large number of the inquiries about office buildings were made, not by affected office workers, but by building managers, contractors, consultants, or company health and safety officers. The IWG's experience in the State of California could help other health departments prepare to face the public's increasing concern about indoor air pollution.

A general methodology is offered by Bostrom et al. (1992) for studying lay people's understanding of the physical, chemical, and biological processes and their response to an environmental hazard. It attempts to characterize people's mental models of a hazard i.e., the sets of principles from which they generate predictions about its behaviour. The organizing device for this methodology is a network representation of expert knowledge about the hazard, emphasizing concepts relevant to risk management. The mental model methodology is illustrated with a set of interviews about the risks of radon. Respondents (N=24) were recruited from several civic groups, which received a monetary contribution in return for their members' participation, or through signs posted at local libraries, in which case payment was direct. The guided interviews were conducted, transcribed and coded into the expert influence diagrams. The results have implications for measuring, predicting, and aiding the public's understanding of environmental hazards.

Alsop and Watts (1997) investigated models of conceptual change learning through a series of cases within informal learning contexts in the UK. These models encompass issues of affect, conation, and self-esteem besides cognitive domain. Four case studies concerning the informal learning of radiation and radioactivity within the members of a rural village in a geographic area in the UK that has high levels of background radiation through naturally occurring radon gas were performed. The adults were selected by using snowball method as part of the larger investigation. The method of data collection was semi-structured interviews, "conversational encounters to a purpose", usually about an hour in length, and later transcribed in full. The obtained interviews were analysed. The emphasis of the study is to examine to which level such model can describe these villagers' engagement with the science involved in a hazard in their daily lives. The model has, however, given rise to some questions and early thoughts for what improved "informal science education" might be; for example: What is the pragmatic relationship between school science and informal science? Does school science provide an adequate base for citizen science?

Whittaker (1988) explores, based on an ethnographic study, one Australian community's popular epidemiology of the role of the environment on health. Together 88 transcribed in-depth open interviews

with residents of Oceanpoint and seven focus group discussions were used. Residents express concern about cancer risks due to contamination from a land dump site and from radioactivity from previous mining activities. Fears concerning cancer in Oceanpoint are linked to feelings about access to power in society. Members of the community experience the lack of power on many levels, from the disregard by authorities of their concerns, to their inability to control and prevent the capitalist development of their community and the subsequent changes to their lifestyle and pollution of their air, water and soil.

Witte et al. (1998) present results of focus groups discussions on risk from radon exposure within African Americans. Nine focus groups were conducted from six counties representing diverse areas in Michigan's lower peninsula. Focus groups were chosen as an appropriate method because they are an especially advantageous means of gathering information on difficult-to-reach populations. Nine group sessions were conducted with a total of 64 participants. Participants were recruited at worksites or churches and were eligible for participation if they smoked or had ever smoked or if they had children under age 12. Ninety-five percent of the participants were African American. The focus group protocol included sections: knowledge of radon, radon testing, and radon reduction; perceived severity of radon, perceived susceptibility of harm from radon, perceived response efficacy of testing and reduction, and perceived self-efficacy toward testing and reduction; radon reduction behaviours in which participants might have engaged; reactions toward existing campaign materials in terms of the level of perceived severity or susceptibility and the level of response and self-efficacy they promoted and suggestions from focus group members on what effective campaign materials should address. Standard focus group analytical procedures were followed: transcription of discussion, development of classification scheme, coding, distribution of coded material discrete tables, and interpretation of the analyses. The knowledge and perceptions results indicated that studies population of African Americans often held inaccurate beliefs regarding radon (e.g., confusing it with carbon monoxide gas), perceived it to be a serious threat, and perceived recommended responses to be inadequate in averting harm. The campaign materials evaluation showed that campaign materials often promote perceptions of threat but not perceptions of efficacy regarding recommended responses. Recommendations are given for public health practitioners.

In Alsop (2001) a quasi-scientific comparative study of two groups of ‘recent school leavers’ in the UK (n = 30) is documented. The participants were all non-science university undergraduates, male and female aged 18-24 and selected at the university programme. Participants from one group have all lived and been educated in a geographic area with higher than average atmospheric radon gas concentrations. In contrast, the participants from the other group all have lived and been educated in areas not associated with elevated radon concentrations. A methodology of Interviews-About-Scenarios (IAS) was used to elicit discussion not only about what conceptual system learners hold, but also how they felt about this knowledge as well. Twenty different scenarios were used and took the form of line drawn pictures, presented on A4 card. The scenarios were developed to facilitate broad discussions in three areas: the general nature and effects of radioactive sources and radiation, the specific nature and effects of radon gas and the dangers associated with radioactivity and radon gas. The interviews were transcribed and analysed based on five stages Grounded Theory methodology. The study seeks to explore if people living with the immediacy and relevance of higher than average levels radioactivity are more knowledgeable and emotionally detached compared to a similar group removed from this health concern. When the two groups were compared, few conceptual and emotional differences were observed. However, the participants faced with higher than average radiation levels were found to be more knowledgeable about the everyday practicalities of living with increased risk due to elevated radon concentrations.

Hamilton (2003) investigates how participants in risk debates draw upon and combine aspects of technical and cultural rationality as broad orientations to risk in expressing their views and formulating persuasive appeals during risk debates. Rhetorical theorist Kenneth Burke’s concept of frames of acceptance is used to analyse a case study involving competing priorities for radium stored at the

Fernald site, a former Department of Energy nuclear weapons facility. A rhetorical analysis is conducted using the transcript from a 1995 public meeting during which local residents and a nuclear medicine expert discussed priorities of Fernald site clean-up versus providing radium stored on site for promising cancer research. Two tensions are identified that fostered disagreement among discussants: the first a tension between a local or global context for the controversy and the second a tension between competing definitions of public participation for this issue.

Scivyer et al. (2005) reports about the pilot study funded by UK government to see if local authorities could be used as a focus for raising public awareness and encouraging remediation of radon risk. The pilot studies were organised with 3 local authorities with high prone radon areas with homes with a greater than 5% probability of being above the Action Level. The contacts with householders were established via different approaches: home visits, radon public venues, roadshow events and telephone connections. The result has been a significant increase in the number of houses measured, with a doubling of the number of houses remediated. The factors that influenced this success were local delivery of advice and support, effective targeting of key groups, optimum use of technical expertise from officials, deployment of simple consistent messages on health risks and remediation methods and sustained support and follow-up contact by the local authority.

Johansson et al. (2007) report on the radon measurement activities at Stockholm House of Science, with aims to introduce nuclear and experimental physics in a way that attracts the attention and interest of the students. These projects give the students the opportunity to use mobile detectors, either in their school, in the House of Science or in their homes. During 2006, 34 radon experiments were organized for school classes or groups of students. There were 21 shorter activities, ten one-day projects and three projects lasting for one or more weeks. Because of the popularity of the radon project, the intention to extend it with the introduction of more mobile detectors was reported.

DiPofi et al. (2001) conducted exploratory qualitative analysis to gain in-sight into perceptions of the threat of radon in the Karst geological region in USA. Five focus groups were conducted with participants from the local communities and surrounding areas recruited with the help of local public health officials, representing a range of demographics of blue collar and white-collar workers, males and females. In total, over 50 individuals participated. Two focus groups were made of up “working class” people with high school educations and on the job skill training, another two focus groups were made up of “white collar” people (e.g., administrators). The fifth focus group was made up of “white collar/upper middle class” people from a specific housing area in central Tennessee which has experienced significant radon problems due to the fact the homes are located on a hillside with great quantities of uranium ore in cavernous rock close to the surface. Focus group outlines were developed to provide contiguity between groups and to explore the facts about the nature of radon awareness and what actions have been taken because of this awareness (both maladaptive and adaptive). Additionally, a broad range of suggestions for increasing the awareness of radon and stimulating behavioural changes as a result of that awareness were obtained.

Immé et al. (2013) present about two programs, promoted from Ministry of Education and University and National Institute of Nuclear Physics (INFN), on scientific dissemination in the field of environmental radioactivity, implemented from 2005 on in Italy. High school students in many Italian regions were involved in particular in indoor radon measurements. With this program students acquired awareness about the risks of inhalation of radon and its progeny and at the same time contributed to carry out radon monitoring, participating to all the experimental phases, from detectors set-up to data analysis. In total about 500 detectors were placed in dwellings and schools in 57 locations. From the evaluation of the participating teachers and students, this kind of activities represents a successful strategy to enhance dissemination of physics, in particular in radioactivity topics.

B. B. Johnson (2017) present the findings from investigation on citizen-preferred options (including any not yet suggested by policy makers) for radon mitigations and difficulties in presenting needed

background information so that policy preferences are reported in valid and reliable way. Focus groups methodology was used with 6 groups averaging 10 people each (in total 60), where groups were recruited from customers of utilities that would be affected by the policy choice (i.e., radon levels of 300–4,000 pCi/L). The focus-group process exposed people to a sequence of materials on radon, risk, objectives of policy and sample policy-description sheet and then asked them for their responses to and questions about information in these materials. As with most focus groups, these group interviews were semi-structured, which means that they used responses from group participants to guide the majority of questions asked, rather than having a fixed set of questions ready beforehand. Focus groups discussions were tape-recorded and transcribed. The results showed both potential benefits of public consultation in widening managers' understanding of policy options, trade-offs, and communication barriers, as well as difficulties that must be addressed to make such consultation easier and more fruitful for all involved.

Groppi (2018) presents an experimental activity that involves 1400 secondary school students involved in radon measurements. Nuclear training kits were distributed to the students with the expectation that they would set up a small-scale radiation laboratory. The kits distributed to the Regione Lombardias schools include passive dosimeters, small plastic boxes to be used as expansion chambers, a fryer to be used as thermostatic bath to develop the dosimeters, and a cheap optical microscope with a simple webcam designed to be interfaced with a standard PC. The experiment proved to be very interesting, and attractive for students.

Momin et al. (2018) sought to determine radon-related knowledge, attitudes, and practices among Realtors (association with real estate trade members in USA) to inform cancer control activities at local and state levels. The focus groups were conducted with members in four states to collect information about knowledge, attitudes, and practices regarding radon. In each of the four states, three focus groups with a total of 12 sets with an average of 5–10 participants were conducted. The four states—Illinois, Minnesota, North Carolina, and Ohio—were chosen because they had a variety of radon policies: from radon notification policies, state managed licensing requirements for radon professionals, and no policies. A focus group moderator guide that included open-ended questions on radon was developed, as well as additional probes to stimulate discussion among participants Realtors reported obtaining information on radon in similar ways, being aware of radon and its characteristics, and dealing with radon issues as a normal part of home sales. Differences in attitudes toward testing varied across states. Realtors in states with radon policies generally expressed more positive attitudes toward testing than those in states without policies. Radon mitigation was identified as an added expense to buyers and sellers. Realtors cited concerns about the reliability and credibility of mitigation systems and installers.

Khan and Chreim (2019) report on perceptions of radon health risk and examines the factors that enable and hinder the adoption of preventive measures among Ottawa-Gatineau residents. Semi-structured interviews with 35 residents with varying educational and income levels were conducted to inquire about their knowledge and perception of radon, and to explore their views of enablers and obstacles to taking action to reduce radon risks. Thematic, inductive data analysis was undertaken. The results indicate that:

1) Residents obtained information on radon from various sources that include the media, their education or occupation, their social network, and home renovation events. Limited references were made to the National Radon Program responsible for testing for radon and informing residents;
2) Awareness of radon risk varied, and the knowledge retained by some residents is insufficient to adequately protect their health;
3) Enablers for taking protective action included: having an understanding of the risk along with health consciousness; caring for family and children; knowing others who had contracted lung cancer and having financial resources. Obstacles consisted of: lack of awareness; cost; lack of home ownership; and potential difficulty in selling the house;
4) Residents attributed primary responsibility to public agencies for disseminating information, and incentivizing or mandating action through more stringent regulation.

Pugliese et al. (2019) investigate the importance of Work-Based Learning experiences of Italian high school students and how some extracurricular basic knowledge may influence the student's intrinsic motivation. The Italian model, named Alternation School-Work (ASW), highlights the partnership between schools and workplaces or real life situations. The experience of about 120 students of three different schools located in Campania Region (South Italy) were considered. The goal has been to educate students on topics such as environmental radioactivity and in particular about the public exposure to radioactivity of natural origin (cosmic rays, radon etc.), in the framework of Astroparticles' School of National Institute of Nuclear Physics, also introducing them to real measurement campaigns. Having improved knowledge about their country's geophysical features, the students have drawn up informative material and a simple survey to propose to the local population in order to understand the level of knowledge on the issue of radioactivity and the consequent perception of risk. The result has been that the students could know and deal with the problem, in a realistic way, from the point of view of scientific research, thanks also to the RadioLab project of National Institute of Nuclear Physics (INFN), through which measurements of the concentration of radon gas activity have been carried out in the buildings of their own school complexes.

König et al. (2014) focuses on the underlying reasons for communication problems between experts and affected members of the public. Exploring the case of a German remediation site with residual radioactive contamination in a residential area, the experts' as well as the residents' perspectives were studied by conducting qualitative interviews with 26 participants (11 residents from local community, 11 experts, 2 with journalists, 2 local people from community gardening area). While it was easier to get in touch with the experts via professional and direct contacts, the recruiting of residents turned out to be more difficult, considering the stressful situation and the sensitivity of preserving privacy. The contacting took place via gatekeeper processes. For the generation of qualitative data, guided interviews and expert interviews were chosen as research methods. The guided interviews included the personal data, the remediation case description, the risk perception, management and communication. The interviews with experts included professional data, general and particular characteristics of the case, risk assessment, reactions from residents and risk communication. All interviews were tape-recorded, transcribed and anonymised. Each interview text was then analysed by qualitative content analysis, in which transcripts were extracted, and the extracts were analysed and interpreted in a circular process.

In analysing the statements of the residents and the experts according to the qualitative content analysis, different category clusters were used. For the residents the categories were: knowledge on the site, risk perception to various contaminations, regulatory aspects and financial issues. For the experts the categories were: Risk assessment and structure of radiation protection policy, role of different key elements (policy, legislation, finance), experiences in risk communication and views of stakeholders. The results indicated a variety of reasons for communication problems on different levels of risk management and risk communication: the regulatory, the communicative and the moral levels. In the observed case, four salient causes for problems in risk communication and risk management emerged: the mismatch in understanding the residents' values, the issue of risk communication in an unforeseen situation, the problem of the regulatory gap between radiation protection and soil protection in regard to legacies with naturally occurring radioactive material in Germany, and the challenge of communicating a highly complex scientific issue to non-scientists.

4.4.2 Some methodological challenges observed in qualitative studies

Here we will present some of the methodological reflections and challenges based on the reviewed articles that used a qualitative approach (including the articles with mixed method design)

Sampling and recruitment of respondents or participants

In qualitative studies, sampling procedures for participants or respondents were often purposeful, convenience or snowball sampling techniques were also common. Participant were recruited from

specific populations, e.g. areas with higher radon concentration (DiPofi et al., 2001; B. B. Johnson, 2017), within the target group of population (Witte et al., 1998) or with different radon policy (Momin et al., 2018) or from particular local population (Khan & Chreim, 2019; Whittaker, 1988). Bostrom et al. (1992) recruited participants from general public by using the monetary contribution to civil society groups or directly to respondents on the public invitation. In observation study, like pilot study (Scivyer et al., 2005), three local authorities in UK with high prone radon areas were involved for direct communication with homes with a greater than 5% probability of being above the Action Level. In several investigations (Groppi, 2018; Immé et al., 2013; Johansson et al., 2007; Pugliese et al., 2019) the participants were selected from the students of the same faculty.

In several cases, the applied sampling technique prevented researchers from generalising their conclusions, which they acknowledged as a limitation of their research. Some studies used purposive snowball sampling. For example, Murphy et al. (2019) used purposive snowball sampling to identify professionals who had the knowledge and experience to inform their research questions. Authors collaborated with state agencies and disseminated the survey link via e-mail, working closely with Colorado-based public and environmental health organizations. The resulting sample was overly homogenous in terms of disciplines of the participants. Martin et al. (2020) recruited their participant at the specific locations and events, which resulted in underrepresentation of rural communities.

Selection of participants for focus groups was well reported in Golding, Krimsky, and Plough (1991): the participants were screened on several criteria including: home ownership; testing status; income; gender; and location of residence and that all the participants were homeowners and residents of the investigated towns. However, the authors stay unclear on the selection method and motivation of participants (for instance by incentives), which are also important to disclose.

The identification of selected documents for analyses of secondary data were not well described. In Cothern (1990) the following statement is given "*numerous articles, papers and discussions in the media have focused on the health consequences of indoor air levels of radon…*". In Macher and Hayward (1991) the data used for analyses were recorded by the Members of the California Interagency Working Group (IWG) on Indoor Air Quality of inquiries they received over a 30-month period from mid-1985 through 1987. Hamilton (2003) used the transcript from a 1995 public meeting during which local residents and nuclear medicine experts discussed priorities of Fernald site clean-up versus providing radium stored on site for promising cancer research.

Focus groups and interviews protocol

Most of the studies using the focus groups and interviews also included some information on the applied protocols. However, some report neither the protocol nor the method to record or analyse the focus groups. The interview guides included typically both closed and open-ended queries (e.g. Khan & Chreim, 2019) on sources of information on radon, views on radon health risk, and enablers and obstacles to taking action related to radon, risk management strategies and risk communication. The questions also requested from participants to provide suggestions on how awareness of radon health risks and actions to reduce such risk could be achieved. In addition, also socio demographic data are usually collected with information on sex, age, education, income, homeownership, and frequently also years of living in the home and smoking habits. There were some examples of good practice. For instance in study of Zierold and Sears (2014) or Zierold and Sears (2015) authors report that they were following a "*semi-structured guide that contained three sections, (1) community strengths and weaknesses, (2) perceptions and beliefs about coal ash and exposure, and (3) perceptions about community health and personal/family health… All discussions were tape recorded and later transcribed verbatim by a medical transcriptionist. Since there are no studies on community populations exposed to coal ash, inductive thematic analysis based on work of Braun and Clarke and Patton] was used to analyze the data from the transcripts." (P.2).*

In articles that applied media content or discourse analysis it is often difficult to assess, what kind of method was used. For instance, Mazur (1987) reported a rather narrative analysis of media reporting related to radon in USA media TV network news reports, newspaper articles and magazine articles (1984-1986), but with not much details on the specific methodology.

Coding of (open-ended) interviews, focus groups or thematic discussions

The coding of the collected data was used in most of the focus groups and interviews investigations. In Bostrom et al. (1992) the expert influence diagrams were used to support the coding. In Alsop (2001) the interviews were analysed based on five stages Grounded Theory methodology. However, for the majority of the studies there was no information on approach to coding available. The authors rather used the analyses of transcribed text, also as part of the presentation of results (e.g. Alsop & Watts, 1997; Whittaker, 1988). In the DiPofi et al. (2008) only findings are presented without the description of the coding method.

When described, the process of coding was usually iterative: as the coding progressed, new codes are added, and some codes are modified. Following such steps, the involved researchers were reviewing the coded interviews, and the code list is developed including themes and subthemes. These patterns or themes were developed in answer to the research questions.

A positive example from a methodological point of view is a study of Hampson et al. (1998) where authors report that the first coder coded the 15 open-ended questions and inter-coder agreement was demonstrated for a randomly selected 20% of the interviews coded independently by a second coder. "*Percentage agreement between the two coders ranged from 73% to 100%. Kappas ranged from .57 to 1.00, and 12 of the 15 were >.70. The first coder's decision was used in all cases. Possible effects of the two different orders of the interview questions were examined by comparing participants' responses on the fixed-response questions across the two orders by one-way between-groups analyses of variance (ANOVA, Fs ranged from 0.24 to 2.99). There were no significant effects, so the data from each order were combined*." (p. 346).

4.4.3 Assessment of trustworthiness in articles that used qualitative methods

As explained in 2.2.1, there are different procedures for assessing rigour (trustworthiness) in qualitative research: *Credibility, Dependability, Confirmability, Transferability, Reflexivity*. The assessment of inter-rater agreement can also be applied in studies with descriptive thematic analysis. Since our review focused solely on the methodological aspects of the papers, we were not able to evaluate how all of the abovementioned criteria were applied in the analysed articles (e.g., for some criteria one would need to analyse theory, methods and results together). We will therefore present some selected examples of how trustworthiness was addressed in the analysed articles.

Inter-rater agreement is often used as measure of reliability in quantitative studies, however, it can also be applied in qualitative studies (e.g., when transcripts are coded into categories or themes). This was performed in several of the articles with the qualitative component (Bostrom, Atman, Fischhoff, & Morgan, 1994; Bostrom et al., 1992; Hampson et al., 1998; Momin et al., 2018).

Khan and Chreim (2019) used inductive approach in their data analysis, so the assessment of the agreement could not be performed. However, they followed an established procedure and adapted their codes: "*Following Braun and Clarke and Miles et al., after familiarization with the transcripts, initial codes that were close to the data were applied. The first author initially coded seven interviews, using descriptive codes. The process of coding was iterative: as this coding progressed, new codes were added, and some codes were modified. Following this step, the second author reviewed the coded interviews, and the two researchers developed a code list that was used to recode the interviews. The first author then continued coding the other transcripts, while also convening with the second author on*

a regular basis to discuss emerging patterns in the data. These patterns or themes were developed in answer to the research questions." (Khan & Chreim, 2019).

Momin et al. (2018) used iterative approach in their analysis, "*We developed a codebook to code the focus group data to ensure a high level of dependability in the analysis. Similar patterns, codes, and themes were identified, which contributed to the rigor and dependability of analysis. … Large segments of the data were coded initially by one coder. Over the course of the analysis, codes were reviewed and compared across transcripts to ensure accurate coding. We also limited the number of codes by condensing some of the codes into larger codes, to ensure organization of data for analysis and utility of codes. A constant comparative method was used, in which the coding strategies and findings were compared across transcripts. A second analyst reviewed the codebooks and examples of how the codebook was applied to the focus group data to establish interrater agreement. The second analyst did not identify any discrepancies in the coding.*"

In several articles, the agreement between the coders was not reported, although applicable (DiPofi et al., 2001; B. B. Johnson, 2017; König et al., 2014; Macher & Hayward, 1991; Witte et al., 1998). In addition, the description of the analysis procedure in these articles and some other articles (Hamilton, 2003; B. B. Johnson, 2017) did not contain much details or was not described at all, violating, therefore, the criteria of *Dependability*.

Confirmability criterion states that it is important to have a clear link between the data and the findings, this can, for instance be demonstrated by the use of quotes in the articles. Some few analysed articles contained quotes from participants to illustrate their findings (Alsop, 2001; Alsop & Watts, 1997; DiPofi et al., 2001; Khan & Chreim, 2019; König et al., 2014; Whittaker, 1988; Witte et al., 1998)

We have only found one article that performed respondent validation and held some feedback sessions after performing interviews and surveys (Murphy et al., 2019), supporting, therefore, the criterion of *Credibility*.

4.4.4 Reflections and recommendations

Qualitative articles or articles with a qualitative component constituted a small proportion of the total body of the reviewed articles. The focus of the articles varied and their majority focused on studying localised target groups (e.g. residents in the area with higher radon concentration, students, end even real estate traders). The results from the reviewed qualitative research in the radon area have indicated responses to the very direct questions which were investigated, like, how the awareness of radon could be increased, what would increase the intention of radon mitigation in homes, how communication activities could be improved. Some studies also contributed with results which bring other dimensions of radon issues: framing of the problem, tension between a local or global context, tension between competing definitions of public participation, access to power in society, long-term governance and continuity of actions.

As the number of participants in qualitative investigations was usually small, the samples were not representative. However, in some cases, better sampling and recruitment strategies could have contributed to better generalisability of the results in the specific context of the studies. Even in qualitative studies that use non-probabilistic sampling techniques, one could try to include all the different categories of citizens to get a broader understanding of the concept in question.

The analyses of the collected data were similar in most of the articles analysed: the data was recorded, transcribed and then analysed by using a coding approach. However, too often authors did not describe or described in not much detail, the procedure for data analysis. Lack of information on how the codes were developed, how data was categorised and how bias was minimised, greatly decreases the reproducibility of the results. At the same time, it also weakens the argument of the study as without knowledge of how the data was analysed, it is hard to judge whether the interpretation was appropriate.

Rigor is as important in qualitative studies as it is in quantitative studies. We did not find a lot of information in the reviewed articles on how *Credibility, Dependability, Confirmability, Transferability, Reflexivity* were ensured and assessed.

Key recommendations for qualitative studies:

- Aim at inclusiveness of different categories in the population sample

Reproducibility

- Describe sampling and recruitment (including incentives for participation)
- Share the research protocol
- Describe the data analysis (categorization, code development, process of analysis)

Trustworthiness

- Inter-coder agreement should be assessed when applicable
- Detailed explanation of all the steps between data and conclusions should be described
- Perform respondent validation as it is an important aspect of credibility
- Use quotes to illustrate findings
- Method, theory, investigator, and data source triangulations should be performed

4.5 Mixed methods

In this sub-chapter we will present the articles that were categorized as those with study design "mixed method". Although in the literature, the definition of mixed method includes studies that applied a combination of several qualitative, or several quantitative methods, for the purpose of this report, we will only address the papers that used a combination of qualitative and quantitative. The results in this chapter will only focus on the way a combination of quantitative and qualitative approaches was applied in the reviewed articles, as specific aspects of quantitative and qualitative methods on their own are discussed in chapters 4.3 and 4.4 respectively.

The 14 articles within our review that used mixed methods approach are presented in Table 7 and are categorized according J.M. Morse et al. (2006). In addition, we describe for each of the mixed-method articles related to societal aspects of radon (N=11) and NORM (N=4) the sequence of the methods used for the research, all qualitative and /or quantitate components of the research and methodological characteristics of these components (see Table 7).

Table 7 - Type of mixed method design in Radon and NORM related SSH articles

Type of mixed method design	Description according to Morse et al. (2006)	Study
QUAL+quan	Qualitative core component of the project (inductive theoretical drive) with a simultaneous quantitative supplementary component.	(B. E. Erickson, 2007d)
QUAL->quan	Qualitative core component of the project (inductive theoretical drive) with a sequential quantitative supplementary component.	(Golding et al., 1991) (Hampson et al., 1998) (M. E. Lee, Lichtenstein, Andrews, Glasgow, & Hampson, 1999) (Murphy et al., 2019) (Petrescu, Petrescu-Mag, & Tenter, 2019) (Zierold & Sears, 2014, 2015; Zierold et al., 2015)

QUAL+qua	Qualitative core component of the project (inductive theoretical drive) with a simultaneous qualitative supplementary component.	
QUAL->qual	Qualitative core component of the project (inductive theoretical drive) with a sequential quality supplementary component.	(Bostrom et al., 1994)
QUAN+ qual	Quantitative core component of the project (deductive theoretical drive) with a simultaneous qualitative supplementary component.	(Mazur, 1987)
QUAN->qual	Quantitative core component of the project (deductive theoretical drive) with a sequential qualitative supplementary component.	(Martin et al., 2020); (D. Ryan & Kelleher, 1998); (Weinstein, Klotz, & Sandman, 1989)
QUAN+quan	Quantitative core component of the project (deductive theoretical drive) with a simultaneous quantitative supplementary component.	(Perko, 2014)
QUAN-> quan	Quantitative core component of the project (deductive theoretical drive) with a sequential quantitative supplementary component.	

* *"**The core component** of the project is the primary, main, or foundational study in your project. It is the method that is used to address the major part of the research question. Think of the core as the backbone of your project, onto which all other components, methods, or strategies will be attached. The core component is always dominant in mixed method studies. The core method must be conducted at a standard of rigor such that, if all else were to fail, it could be published alone." (J. M. Morse & Niehaus, 2016, p. 23)*

** *"**The Supplemental Component** Although the core component is always dominant, complete (i.e., scientifically rigorous), and can stand alone, the supplemental component is conducted only to the extent that the researcher obtains the information needed and could not be published alone. We therefore refer to the methodological research tool used to obtain supplementary information as a strategy, rather than a method. The supplemental project, conducted alongside the core method, is relatively independent but joins the main project at the point of interface, or where the two methods come together."* (J. M. Morse & Niehaus, 2016, p. 24)

4.5.1 Sequence of methods used in the research

Most of the articles used qualitative methods followed by quantitative methods. For instance, the article of Golding et al. (1991) first applied focus groups which were followed by embedded experiment in a telephone interviews. Also M. E. Lee et al. (1999) started a study with focus groups, followed by a longitudinal questionnaire with an integrated experiment with three stimuluses. Hampson et al. (1998) used mental model approach with semi-structured interviews followed by a quantitative survey. Another study applying first qualitative method which was followed by quantitative method is Murphy et al. (2019). Authors first conducted semi-structured interviews, analysed the content of open-ended responses about "Other" environmental hazards and community health concerns and contributing factors, and had a feedback session with the participants. All these helped them to develop an online survey. Also Zierold and Sears (2014) conducted interviews first, followed by a survey. The study of Zierold and Sears, reported in three similar publications Zierold and Sears (2015), Zierold and Sears (2015) and Zierold and Sears (2015) also applied first a focus group method, followed by a questionnaire.

Several authors started with a quantitative method and continued the study with a qualitative method. Martin et al. (2020) first applied an empirical research with a survey and continued with open Interviews and discussion groups. D. Ryan and Kelleher (1998) first applied closed questionnaire and continued a research with semi-structured interviews. Weinstein et al. (1989) started their study first with a survey and continued the research with open interviews.

The only study that mixes different quantitative methods simultaneously is the one of Perko (2014). The author combines media content analysis of articles published in print media and two public opinion surveys, one for a general population and one for experts.

Another approach, quantitative and qualitative simultaneously was applied by Mazur (1987). The authors applied qualitative media content (discourse) analysis of narratives and stories related to radon in early 80's and continued with a qualitative method – media content analysis of press coverage in USA media: TV network news reports, newspaper articles and magazine articles (1984-1986). Also study of B. E. Erickson (2007d) first applied unstructured or loosely structured interviews and which lead to a quantitative questionnaire.

The only study that applied qualitative core component of the project with a sequential quality supplementary component is the one of Bostrom (Bostrom et al., 1994)et. al (1994). They first applied mental model approach, followed by another mental model approach upgraded by questionnaire and test.

A specific method was used in the study of Mardis, Guimond, and Fisher (1988). The authors applied a synthesis level for an overview of different radon programme's results.

For more detailed description of studies and mixed methods used see Table 8.

Table 8 - In-depth analysis of methods applied in the mixed methods articles

Mixed method study (ref.)	Sequence of methods and topic (radon or norm)	Qualitative component	Method for the qualitative component	Quantitative component	Method for the quantitative component	Methodological Challenges (according to authors)
(Golding et al., 1991)	QUAL->quan *(Radon)*	6 **focus groups** with homeowners	Protocol was used to develop technical and narrative newspaper articles (risk communication material). The participants were screened on the following criteria: home ownership; testing status; income; gender; and location of residence.	**Experiment** with two series of articles on radon were placed in the local newspapers of two communities + community as a control group **Telephone longitudinal survey** in two waves in order to measure baseline (N= 491) and the effect (N=238): to identify any changes in knowledge, awareness, and attitudes that might be due to the experimental intervention	**Experiment: technical** series presented authoritative, factual **risk information**, in the scientific style of the passive voice with generalized and impersonal language. The **narrative** series consisted of dramatized accounts of individuals making decisions about radon testing and mitigation, written in a more personal style (story telling format) **Telephone survey**: were conducted before and after publication of the two series to evaluate their relative effectiveness in terms of readership, awareness, knowledge, attitudes, and testing and mitigation behaviour.	Small **size of the follow-up** samples was a limiting factor in drawing definitive conclusions about the relative effectiveness of the two formats. The **intervention may need to be more extensive**, using multimedia approaches over (only newspaper was used), prolonged periods (they were 4 days long), to increase public response and highlight any differences in effect. The **difference in effectiveness between the technical and narrative formats** may be too low. Either it is too difficult

						to make the narrative and technical formats sufficiently different to elicit measurable public responses, without sacrificing authenticity, or people truly do not respond differentially to technical and narrative formats.
(Hampson et al., 1998)	QUAL->quan *(Radon)*	**Mental model approach with Semi-structured Interviews**	**Protocol** with open-ended questions followed by more specific questions: feeling about various kinds of air pollutants, followed by sections on radon, smoking and questions of combination of radon and smoking. - responses were **coded** by two independent coders	**Survey/Questionnaire**	**Survey/questionnaire**: pre-brochure questionnaire with The Psychometric Approach and Optimistic Bias (assessing risk perceptions about smoking, reading a brochure about the synergistic health risk of radon and smoking), post-brochure questionnaire (assessing risk perceptions about radon, and the combination of radon and smoking), and a background survey. Risk perception of radon, smoking and combination of radon & smoking were assessed on nine scales assessing of dread risk and unknown risk, optimistic bias, participants rated the likelihood of health consequences from each hazard separately for	A measurement of the synergetic risk perception of radon & smoking may be improved. In this study, participants rated the single and combined hazards separately, and **were not explicitly asked to compare the risk of the single hazard with the risk of the combined hazard**. It is possible that a more direct approach, in which participants are asked to make comparisons between combined versus single hazards, would produce greater perceived risk for

					themselves, others in their house, and others in general or in their neighbourhood. (Seven-step scales and "Don't know" option.) Section on background variables contained demographic questions, whether they had ever tested for radon, and whether they or others in the home were smokers.	combinations of hazards conclude authors.
(M. E. Lee et al., 1999)	QUAL->quan *(Radon)*	**Focus groups (or structured interviews)**	**3 Focus groups**: 10-12 people in a group	**Longitudinal questionnaire with an integrated experiment with three stimuluses** (booklet: 301 indiv,155 households / pamphlet: 349 indiv, 191 household / telephone: 355 indiv, 180 household) (the 2nd wave was conducted 3 month after the 1st.)	**Questionnaire**: baseline questions (assessing the demographic characteristics and smoking habits of household members).	Methodological limitations of this study are the **reliance on self-reports of smoking and risk reduction actions and the short-term follow-up.** Long-term (i.e., 12-month) follow-up data are needed to examine sustained quitting and other risk reduction outcomes.
(Mardis et al., 1988)	Synthesis level *(Radon)*	**The multiple method: an overview**	**Overview** of programme's results.			
(Martin et al., 2020)	QUAN->qual *(Radon)*	**Survey**	29-question **survey**: three main components: (a) parent or guardian awareness of radon	**Open Interview** **Discussion Group**	**Interview** of two (2) parents for their views and concerns about radon in schools. A thematic content analysis of the **discussion group**	Relatively **small study was not powered to detect small differences** in support for radon

			and its health effects, (b) parent or guardian awareness of radon in schools, and (c) participant demographics. (Likert-like scales)		manuscript was conducted using the Framework Method in which all meaningful text was assigned a nonpredetermined code. A master list of all codes was maintained, and the codes were organized into a matrix by theme (Gale et al., 2013). A subset of themes was selected to be highlighted in this text.	testing based on income or level of education. The predominant recruitment of participants at locations and events near one city resulted in a **disproportionate representation** from the most populous county over other, more rural counties. The cross-sectional study design prevented authors from being able to establish causation between increased knowledge about radon testing and increased support for mitigation.
(Mazur, 1987)	QUAN+ qual *(Radon)*	**Media content/discourse analysis**	Qualitative media contend (discourse): narratives and stories related to radon in early 80'	**Media content analysis**	Press coverage in USA media TV network news reports, newspaper articles and magazine articles (1984-1986)	
(Murphy et al., 2019)	QUAL->quan *(Radon)*	**Semi structured interviews** **Content analysis**	**Interviews:** 15 professionals from public (n = 9), academic (n = 4), and private (n = 2)	**Online survey**	**Online survey:** 47 professionals, from 40 public agencies from 34	

		Feedback session	sectors were interviewed. Purposive snowball sampling to identify professionals who had the knowledge and experience to inform the research questions. Analysis of interviews: Authors aggregated responses and analyzed interview notes to determine commonly mentioned environmental issues and resources, data, or regulations needed to address these issues. Interviews reviewed results and provided insight for the next phases of the study. **Content analysis** was conducted on open-ended responses about "Other" environmental hazards and community health concerns and contributing factors.		counties filled in an online survey. Authors disseminated the survey link via e-mail, working closely with Colorado-based public and environmental health organizations.	

			Feedback session: 60 participants (presenting results)			
(Perko, 2014)	QUAN+quan *(Radon)*			**Media content analysis,** **Survey**	Quantitative and qualitative **content analyses** of 51 media articles related to "Fukushima" and "nuclear* in Belgian print media. **Survey:** CAPI = general population (N= 1020), CAWI experts (N = 332)	**Formulation of radon** as "*natural radiation (e.g. cosmic radiation or radon)"* may cause lower risk perception (suggests minimization of the radon risk)
(Petrescu et al., 2019)	QUAL->quan *(Radon/NORM)*	**Interview**	The investigated community was composed of 15 households and one interview was taken in each of them, thus covering the entire community. An interview lasted between 30 and 60 min.	**Survey**	**Variables measured**: Subjective level of sustainable development: Respondent's health status, Respondent's level of formal education, Employment opportunities for respondent a, Respondent's income level per family per month, Respondent's expenses distribution, Quality of respondent's relationship with local authorities (police, city hall, etc.), Quality of respondent's relationship with most of the people in your village, Discrimination felt by respondent, Optimism level regarding respondent's future, Respondent's life quality (Cantril's ladder of life quality), Income level of the inhabitants, Education level of inhabitants, Drinking water	

					quality, Quality of medical services, Quality of educational services, Quality of environmental components (air, water soil), Radioactive pollution level: Radiation level, Radioactive pollution effect: Perception of radiation effect on health in the community. -negotiation power: Existence of a bargaining asset: an offer attractive to the other party, Attractiveness of respondent's offer, Amount of money requested in exchange for accepting to keep on living in the community (in case such a negotiation would take place), Non-monetary compensation requested in exchange for accepting to keep on living in the community (in case such a negotiation would take place), Respondent's right to demand and to negotiate for better living conditions, Desire to move somewhere else, Responsibility of other party for the current economic situation in the community, ETC... Awareness of radiation effect on health, Awareness radiation source: uranium	

					mine, Awareness of effects existence, Awareness of types of effects	
(D. Ryan & Kelleher, 1998)	QUAN->qual *(Radon)*	**Closed questionnaire**	140 respondents: The questionnaire was a two-page document containing 9 closed Q. 6 related to die householders' testing and mitigation experiences, any problems encountered, methods employed and the costs incurred. 2 Q related to the participants' attitude to and perception of radon as a hazardous substance. 12 true/false radon knowledge items. The overall response rate of the remainder was 61% (141 of 233 eligible households)	**Semi-structured interviews**	Face-to-face semi-structured interview (14 respondent out of 140) **Content**: centred on householders' concerns about health, the measurement and remediation experiences and any perceived barriers to implementing change.	**Recall** of household levels of radon by participants themselves and level of action taken **was very poor**. Consequently, there were a lot of don't know answers.
(Weinstein et al., 1989)	QUAN->qual *(Radon)*	**Survey**	(359 respondents contacted, 141 returned Q)	**Open interviews**	16 interviews with the following open discussion points/Q:	Because the identities of residents in the monitoring program were **confidential**, the

					(1) Is information likely to diffuse steadily through the population? (2) Are information needs being met? (3) How much guidance is needed?	authors could not recruit the respondents directly. Instead, a letter describing the project was mailed by authorities to all program participants, along with a postcard they could return to us indicating their willingness to take part. This method of recruitment, although necessary for ethical reasons, resulted in a **Relatively low response rate**; 47.3% returned postcards. Those participants were also **over-representative for educational** level.
(B. E. Erickson, 2007d)	QUAL+quan *(Radon)*	**Unstructured or loosely structured interviews**	64 interviews	**Questionnaire**	Demographic and health data questions, the questionnaire asks for written comments	Author was challenged with a **self-selected population**, and her informants were those whose visits happened to coincide with the author's visits. Due to this she needed to combine

						the qualitative method with quantitative.
(Zierold & Sears, 2015)	QUAL->quan *(NORM)*	**Focus groups**	5 focus groups with 26 adults were conducted. A semi-structured guide that contained three sections, (1) community strengths and weaknesses, (2) perceptions and beliefs about coal ash and exposure, and (3) perceptions about community health and personal/family health, was used for the focus groups.	Cross-sectional **survey**	231 respondents, 39 questions that concentrated on coal ash exposure, health conditions, and health behaviours, such as smoking and wearing personal protective equipment when cleaning. Thirty-eight of the questions were multiple choice, and the final question was open-ended that was asked to respondents to describe how they knew they were exposed to coal ash. (20–30 minutes)	Although all members of the community were encouraged to participate in this study, the members that did participate might **not be representative** of the entire community. The sample may be **more knowledgeable** about coal ash or may be more affected by coal ash or have less fear about retribution from the company. The study might **not be generalizable** to other communities because they recruited only participants who lived near a large coal ash storage site.
(Zierold & Sears, 2014)	QUAL->quan *(NORM)*	**Focus groups**	5 focus groups: A semistructured guide was used that contained three sections: (1) community strengths	**Questionnaire**	At the end of the each focus group, each participant completed a questionnaire that asked about length of time in the community, health, children's health,	The participants that took part in the focus group might **not be representative** of the entire community; they may be affected

			and weaknesses, (2) perceptions and beliefs about coal ash and exposure, and (3) perceptions about community health and personal/family health. The discussions were taped and two additional study team members took notes regarding the conversation and dynamics of the group. The shortest group lasted 50 min and the longest group lasted 1.5 h. The FG were transcribed verbatim and we compared the text with the notes for consistency.		smoking history, and activities related to exposure such as time spent outside, amount of time windows opened.	by coal ash, be more knowledgeable about coal ash, or have children that are suffering from a health condition.
(Zierold et al., 2015)	QUAL->quan *(NORM)*	**Focus groups**	5 focus groups with 26 adults were conducted. A semi-structured guide that contained three sections, (1) community strengths and weaknesses, (2) perceptions and beliefs about coal	Cross-sectional **survey**	231 respondents, 39 questions that concentrated on coal ash exposure, health conditions, and health behaviours, such as smoking and wearing personal protective equipment when cleaning. Thirty-eight of the questions were multiple choice, and the final question	Although all members of the community were encouraged to participate in this study, the members that did participate might **not be representative** of the entire community. The sample may be

			ash and exposure, and (3) perceptions about community health and personal/family health, was used for the focus groups.		was open-ended that was asked to respondents to describe how they knew they were exposed to coal ash. (20–30 minutes)	**more knowledgeable** about coal ash or may be more affected by coal ash or have less fear about retribution from the company. The study might **not be generalizable** to other communities because they recruited only participants who lived near a large coal ash storage site.
(Bostrom et al., 1994)	*QUAL->qual* (Radon)	Mental model approach	Evaluation of 3 radon brochures: (a) a concurrent evaluation using think-aloud protocols (b) a multiple-choice test (c) a true-false (TF) test derived from mental models interviews.	Mental model approach with questionnaire	Evaluation of 3 radon brochures: open-ended recall questions, problem-solving questions, and the two closed-ended tests	

4.5.2 Some methodological challenges in mixed method articles

In the next paragraphs we describe some selected methodological observations that may have positive negative influence on the methodological quality. It is worth noting that these challenges are not specific to the mixed methods design.

In longitudinal studies with follow up questionnaires, researchers often have a problem to engage an appropriate number of participants in the follow-up wave, which results in so-called attrition problems. For instance in study of Golding et al. (1991) the response rate of questionnaires for follow up were 21.6%, 18.8%, 62.9% in three towns included in the study. Small size of the follow-up samples was recognized in this study as a limiting factor in drawing definitive conclusions about the relative effectiveness of the two radon risk communication formats. In addition, the delay between the initial study and the follow-up study can be a methodological challenge. This was recognized in a study of M. E. Lee et al. (1999), where authors surveyed respondents the second time after three months. They conclude that 12 months for the second wave may be better since they are measuring behavioural change (quitting smoking).

Researchers are challenged with low or no significance of experimental results. For instance in some studies with an objective to measure effectiveness of communication interventions by using experiments researchers suspect that duration of the intervention would need to be longer (Hampson et al., 1998) or stronger (Hampson et al., 1998).

Representativeness is in many studies a challenge. For instance, in study of Martin et al. (2020) paper surveys were distributed to family and paediatric medicine clinics, one grocery market and one grocery store, while online surveys were distributed via social media. Due to this Martin et al. (2020) report that the predominant recruitment of participants at locations and events near one city resulted in a disproportionate representation from the most populous county over other, more rural counties and the population of survey participants was relatively homogeneous with the majority being white, well-educated, and women above the age of 30. In studies of Zierold and Sears (2015), Zierold and Sears (2014) and Zierold et al. (2015) although all members of the community were encouraged to participate in the study, the members that did participate are not representative of the entire community. The sample may be more knowledgeable about coal ash or may be more affected by coal ash or have less fear about retribution from the company. The study is not generalizable to other communities because they recruited only participants who lived near a large coal ash storage site.

A formulation of radon as "*natural radiation (e.g. cosmic radiation or radon)"* in a survey may cause lower risk perception (suggest minimization of the radon risk) as recognised by Perko (2014).

Another challenge is related to recall of household levels of radon by participants themselves and level of action taken which was very poor. Consequently, there were a lot of don't know answers in questionnaire D. Ryan and Kelleher (1998).

In the article by Weinstein et al. (1989) the identities of residents in the monitoring program were confidential, due to this the authors could not recruit the respondents directly. Instead, a letter describing the project was mailed by authorities to all program participants, along with a postcard they could return to us indicating their willingness to take part. This method of recruitment, although necessary for ethical reasons, resulted in a relatively low response rate; 47.3% returned postcards. Those participants were also not-representative for educational level.

In the article by B. E. Erickson (2007d) the author was challenged with a self-selected population in her interviews, and her informants were those whose visits happened to coincide with the author's visits. Due to this she needed to combine the qualitative method with quantitative (questionnaire).

4.5.3 Reflections and recommendations:

Several studies in the review used a mixed methods design in order to investigate the complexity of people's attitudes and behaviour related to exposure to natural radiation, which could not be answered using a single method.

Most of the articles used qualitative methods followed by quantitative methods. This is especially useful if the topic has little been studied before. First, the researcher can identify questions and answering categories based on what respondents mention in interviews or focus groups. Then the frequency of these thoughts or behaviours in the population can be assessed through a generalizable quantitative study.

In some articles in the review the sequence was reversed. Such design is useful if the author wants to generalize findings, but also delve deeper into why certain answers were given or what exactly they entail.

However, it is important to realize that studies using two or more quantitative, or two or more qualitative methods can also be considered mixed method studies. Such studies also leverage the advantages and compensate for the disadvantages of individual methods.

Lastly, description of the population, sampling strategy, recruitment procedures, measurement tools and results, is equally important for both quantitative as well as qualitative studies. Quality assessments unique to the design, such as reliability (quantitative) or credibility (qualitative), should be performed and reported also. Only then replicability and verifiability are possible.

Key recommendations for mixed method studies

- Detailed method descriptions of all components will contribute to reproducibility of the study
- If quantitative component is present – probabilistic sampling is recommended
- Aim at selecting a representative sub-sample for interviews and focus groups
- The rigor of all study design components should be ensured

5. Discussion and conclusions

Key take-home messages:

- Lack of social science, NORM and comparative studies should be addressed.
- Attitudes and behaviours of sub-populations could differ from those of general public and are interesting to investigate. Methods and scales should be adapted accordingly.
- Use of multiple methods and innovative methods can supplement traditional methods with additional insights.
- Accurate selection and description of sampling strategy, measurement tools, research protocols and data analysis procedures are crucial in all types of studies
- Ethical aspects should be recognized and addressed

The systematic review of articles conducted within the field of radon and NORM showed lack of research on societal aspects of radon and NORM exposure situations.

Studies were primarily conducted on the local or regional level. Only in one article was a survey carried out in two countries. NORM was generally investigated on a geographically lower level than radon, reflecting the need to capture proximity to NORM industries, and that the exposure problem is highly concentrated. However, 9 out of 10 articles in this review investigated radon.

Furthermore, 7 out of 10 studies were conducted in the United States of America and only 28 articles were from European Union and the United Kingdom. This could reflect that studies conducted in European countries might have been published as internal reports and not in journals and thus fell out of the scope of this review.

To conclude, an important preliminary conclusion of our systematic review is that social science studies, and in particular comparative and NORM studies, are scarce. Thus, there is a potential for new research that can help to elucidate the societal aspects of radiation exposure on populations in diverse contexts.

In this review, eight out of ten articles studied the general population. While this is the main population affected by natural radiation, it would also be interesting to study sub-populations such as experts, politicians and especially workers in NORM or radon prone areas. Such sub-populations could differ in attitudes and behaviours from the general public. However, it is important to consider here is that strategies, methods, concepts and scales have to be uniquely adapted to the needs and capacities of the populations under observation.

Traditional, long standing, methods were used to collect data. In the quantitative studies, primarily surveys and experiments were used, while in the qualitative studies, interviews and focus groups were used most frequently.

It is important that researchers remain aware of the unique advantages and disadvantages of each method and that so they can choose methods accordingly, in support of the research aim. A multi-method approach can help leverage the unique method strengths and generate insights that may not be obtained using a single method. More innovative methods such as the citizen science approach could also offer additional insights.

In the future studies on societal aspects of radon and NORM within the RadoNorm project and beyond, researchers should pay attention to accurate selection and description of the sample strategy, measurement tools and results. For the qualitative investigations it is very important to choose the most appropriate method for the objective of the study, develop and test protocols to allow for improvement and disclose the process of data analysis and interpretation. Quality assessments for all types of study designs should be performed and reported. As for any scientific study, the procedures for ethical approval data management should be followed and ethical issues addressed and reflected upon in each research project.

This systematic review of methodological state-of-the-art will serve as a great starting point for development of methodological guidelines for social and human research in the field of radon and NORM, as well as new methods and approaches for investigating affected populations and stakeholders.

6. Acknowledgements

We would like to thank Johanne Longva at the NMBU library for her help with the development of the search protocol. NMBU acknowledges the support of the Research Council of Norway (RCN) through its Centres of Excellence funding scheme, project number 223268, and project number 313070.

Appendix A. Search protocols

SEARCH 1

Topic	Medline text search	Web of Science text search	Scopus text search
NORM	radioactiv*.tw.	radioactiv*	radioactiv*
NORM	((natural adj2 (radiation or "radioactive material")) or tenorm or residue or remainder or leftover or waste or oil or gas or water or phosphate* or fuel* or geothermal or building* or "flying ash" or mining or mine or "NORM industries" or "building material*" or "alum shale" or (environment* adj1 remediation)).tw.	((natural NEAR/1 (radiation OR "radioactive material")) OR tenorm OR residue OR remainder OR leftover OR waste OR oil OR gas OR water OR phosphate* OR fuel* OR geothermal OR building* OR "flying ash" OR mining OR mine OR "NORM industries" OR "building material*" OR "alum shale" OR (environment* NEAR/0 remediation))	((natural W/1 (radiation OR "radioactive material")) OR tenorm OR residue OR remainder OR leftover OR waste OR oil OR gas OR water OR phosphate* OR fuel* OR geothermal OR building* OR "flying ash" OR mining OR mine OR "NORM industries" OR "building material*" OR "alum shale" OR (environment* W/0 remediation))
Method1	(((field or case or comparative or cohort or archival) adj2 stud*) or ((network or content or sentiment or meta or framework or media or discourse or morphological or text* or conversation or narrative) adj2 analysis) or ((systematic or meta) adj2 review) or ((mixed or mental or mixed or delphi or q or economic) adj2 method*) or "delphi techniq*" or "focus group*" or "repertory grid" or "analytic induction" or "life history*" or historiography or "socio mapping" or "feeling thermometer" or "cybermethod*" or "participatory action" or bibliograph* or questionnaire* or "secondary data" or "e-research" or "memory work" or interview* or observation* or ethnography or phenomenolog* or RCT or "randomized controlled	(((field OR case OR comparative OR cohort OR archival) NEAR/2 stud*) OR ((network OR content OR sentiment OR meta OR framework OR media OR discourse OR morphological OR text* OR conversation OR narrative) NEAR/2 analysis) OR ((systematic OR meta) NEAR/0 review) OR ((mixed OR mental OR mixed OR delphi OR q OR economic) NEAR/2 method*) OR "delphi techniq*" OR "focus group*" OR "repertory grid" OR "analytic induction" OR "life history*" OR historiography OR "socio mapping" OR "feeling thermometer" OR "cybermethod*" OR "participatory action" OR bibliograph* OR questionnaire* OR "secondary data" OR "e-research" OR "memory work" OR interview* OR observation* OR ethnography OR phenomenolog* OR RCT OR "randomized controlled	(((field OR case OR comparative OR cohort OR archival) W/2 stud*) OR ((network OR content OR sentiment OR meta OR framework OR media OR discourse OR morphological OR text* OR conversation OR narrative) W/2 analysis) OR ((systematic OR meta) W/2 review) OR ((mixed OR mental OR mixed OR delphi OR q OR economic) W/2 method*) OR "delphi techniq*" OR "focus group*" OR "repertory grid" OR "analytic induction" OR "life history*" OR historiography OR "socio mapping" OR "feeling thermometer" OR "cybermethod*" OR "participatory action" OR bibliograph* OR questionnaire* OR "secondary data" OR "e-research" OR "memory work" OR interview* OR observation* OR ethnography OR

	trial*" or workshop or "public opinion" or panel* or omnibus or poll or triangulation or hermeneutic).tw.	trial*" OR workshop OR "public opinion" OR panel* OR omnibus OR poll OR triangulation OR hermeneutic)	phenomenolog* OR RCT OR "randomized controlled trial*" OR workshop OR "public opinion" OR panel* OR omnibus OR poll OR triangulation OR hermeneutic)

SEARCH 2

Topic	Medline tekstordsøk	Web of Science tekstordsøk	Scopus tekstordsøk
NORM	radioactiv*.tw.	radioactiv*	radioactiv*
NORM	((natural adj2 (radiation or "radioactive material")) or tenorm or residue or remainder or leftover or waste or oil or gas or water or phosphate* or fuel* or geothermal or building* or "flying ash" or mining or mine or "NORM industries" or "building material*" or "alum shale" or (environment* adj1 remediation)).tw.	((natural NEAR/1 (radiation OR "radioactive material")) OR tenorm OR residue OR remainder OR leftover OR waste OR oil OR gas OR water OR phosphate* OR fuel* OR geothermal OR building* OR "flying ash" OR mining OR mine OR "NORM industries" OR "building material*" OR "alum shale" OR (environment* NEAR/0 remediation))	((natural W/1 (radiation OR "radioactive material")) OR tenorm OR residue OR remainder OR leftover OR waste OR oil OR gas OR water OR phosphate* OR fuel* OR geothermal OR building* OR "flying ash" OR mining OR mine OR "NORM industries" OR "building material*" OR "alum shale" OR (environment* W/0 remediation))
Method2	(survey* OR experiment*)	(survey* OR experiment*)	(survey* OR experiment*)
Human subjects	(public* OR citizen* OR participant* OR respondent* OR resident* OR person* OR stakeholder*)	(public* OR citizen* OR participant* OR respondent* OR resident* OR person* OR stakeholder*)	(public* OR citizen* OR participant* OR respondent* OR resident* OR person* OR stakeholder*)

SEARCH 3

Topic	Medline tekstordsøk	Web of Science tekstordsøk	Scopus tekstordsøk
Radon	radon	radon	radon
Method1	(((field or case or comparative or cohort or archival) adj2 stud*) or ((network or content or sentiment or meta or framework or media or discourse or morphological or text* or conversation or narrative) adj2 analysis) or	(((field OR case OR comparative OR cohort OR archival) NEAR/2 stud*) OR ((network OR content OR sentiment OR meta OR framework OR media OR discourse OR morphological OR text*	(((field OR case OR comparative OR cohort OR archival) W/2 stud*) OR ((network OR content OR sentiment OR meta OR framework OR media OR discourse OR

	((systematic or meta) adj2 review) or ((mixed or mental or mixed or delphi or q or economic) adj2 method*) or "delphi techniq*" or "focus group*" or "repertory grid" or "analytic induction" or "life history*" or historiography or "socio mapping" or "feeling thermometer" or "cybermethod*" or "participatory action" or bibliograph* or questionnaire* or "secondary data" or "e-research" or "memory work" or interview* or observation* or ethnography or phenomenolog* or RCT or "randomized controlled trial*" or workshop or "public opinion" or panel* or omnibus or poll or triangulation or hermeneutic).tw.	OR conversation OR narrative) NEAR/2 analysis) OR ((systematic OR meta) NEAR/0 review) OR ((mixed OR mental OR mixed OR delphi OR q OR economic) NEAR/2 method*) OR "delphi techniq*" OR "focus group*" OR "repertory grid" OR "analytic induction" OR "life history*" OR historiography OR "socio mapping" OR "feeling thermometer" OR "cybermethod*" OR "participatory action" OR bibliograph* OR questionnaire* OR "secondary data" OR "e-research" OR "memory work" OR interview* OR observation* OR ethnography OR phenomenolog* OR RCT OR "randomized controlled trial*" OR workshop OR "public opinion" OR panel* OR omnibus OR poll OR triangulation OR hermeneutic)	morphological OR text* OR conversation OR narrative) W/2 analysis) OR ((systematic OR meta) W/2 review) OR ((mixed OR mental OR mixed OR delphi OR q OR economic) W/2 method*) OR "delphi techniq*" OR "focus group*" OR "repertory grid" OR "analytic induction" OR "life history*" OR historiography OR "socio mapping" OR "feeling thermometer" OR "cybermethod*" OR "participatory action" OR bibliograph* OR questionnaire* OR "secondary data" OR "e-research" OR "memory work" OR interview* OR observation* OR ethnography OR phenomenolog* OR RCT OR "randomized controlled trial*" OR workshop OR "public opinion" OR panel* OR omnibus OR poll OR triangulation OR hermeneutic)

SEARCH 4

Topic	Medline tekstordsøk	Web of Science tekstordsøk	Scopus tekstordsøk
Radon	radon	radon	radon
Method2	(survey* OR experiment*)	(survey* OR experiment*)	(survey* OR experiment*)
Human subjects	(public* OR citizen* OR participant* OR respondent* OR resident* OR person* OR stakeholder*)	(public* OR citizen* OR participant* OR respondent* OR resident* OR person* OR stakeholder*)	(public* OR citizen* OR participant* OR respondent* OR resident* OR person* OR stakeholder*)

SEARCH1

Database: **Web of Science**
Date: **23.11.2020**
Search result: **1665**

AB=(radioactiv*) AND AB=((natural NEAR/1 (radiation OR "radioactive material")) OR tenorm OR residue OR remainder OR leftover OR waste OR oil OR gas OR water OR phosphate* OR fuel* OR geothermal OR building* OR "flying ash" OR mining OR mine OR "NORM industries" OR "building material*" OR "alum shale" OR (environment* NEAR/0 remediation)) AND AB=(((field OR case OR comparative OR cohort OR archival) NEAR/2 stud*) OR ((network OR content OR sentiment OR meta OR framework OR media OR discourse OR morphological OR text* OR conversation OR narrative) NEAR/2 analysis) OR ((systematic OR meta) NEAR/0 review) OR ((mixed OR mental OR mixed OR delphi OR q OR economic) NEAR/2 method*) OR "delphi techniq*" OR "focus group*" OR "repertory grid" OR "analytic induction" OR "life history*" OR historiography OR "socio mapping" OR "feeling thermometer" OR "cybermethod*" OR "participatory action" OR bibliograph* OR questionnaire* OR "secondary data" OR "e-research" OR "memory work" OR interview* OR observation* OR ethnography OR phenomenolog* OR RCT OR "randomized controlled trial*" OR workshop OR "public opinion" OR panel* OR omnibus OR poll OR triangulation OR hermeneutic)

Database: **Scopus**
Date: **23.11.2020**
Search result: **9445**

TITLE-ABS-KEY(radioactiv*) AND TITLE-ABS-KEY((natural W/1 (radiation OR "radioactive material")) OR tenorm OR residue OR remainder OR leftover OR waste OR oil OR gas OR water OR phosphate* OR fuel* OR geothermal OR building* OR "flying ash" OR mining OR mine OR "NORM industries" OR "building material*" OR "alum shale" OR (environment* W/0 remediation)) AND TITLE-ABS-KEY(((field OR case OR comparative OR cohort OR archival) W/2 stud*) OR ((network OR content OR sentiment OR meta OR framework OR media OR discourse OR morphological OR text* OR conversation OR narrative) W/2 analysis) OR ((systematic OR meta) W/2 review) OR ((mixed OR mental OR mixed OR delphi OR q OR economic) W/2 method*) OR "delphi techniq*" OR "focus group*" OR "repertory grid" OR "analytic induction" OR "life history*" OR historiography OR "socio mapping" OR "feeling thermometer" OR "cybermethod*" OR "participatory action" OR bibliograph* OR questionnaire* OR "secondary data" OR "e-research" OR "memory work" OR interview* OR observation* OR ethnography OR phenomenolog* OR RCT OR "randomized controlled trial*" OR workshop OR "public opinion" OR panel* OR omnibus OR poll OR triangulation OR hermeneutic)

Database: **Medline**
Date: **23.11.2020**
Search result: **1225**

#	Searches	Results	Type
1	Radon/ or radon.mp.	8133	Advanced
2	(((field or case or comparative or cohort or archival) adj2 stud*) or ((network or content or sentiment or meta or framework or media or discourse or morphological or text* or conversation or narrative) adj2 analysis) or ((systematic or meta) adj2 review) or ((mixed or mental or mixed or delphi or q or economic) adj2 method*) or "delphi techniq*" or "focus group*" or "repertory grid" or "analytic induction" or "life	2776440	Advanced

	history*" or historiography or "socio mapping" or "feeling thermometer" or "cybermethod*" or "participatory action" or bibliograph* or questionnaire* or "secondary data" or "e-research" or "memory work" or interview* or observation* or ethnography or phenomenolog* or RCT or "randomized controlled trial*" or workshop or "public opinion" or panel* or omnibus or poll or triangulation or hermeneutic).tw.		
3	Public Opinion/	18776	Advanced
4	"Surveys and Questionnaires"/	475182	Advanced
5	Interview/	29398	Advanced
6	Cohort Studies/	272356	Advanced
7	Focus Groups/	30791	Advanced
8	Observational Study/	88323	Advanced
9	"Systematic Review"/	139485	Advanced
10	Delphi Technique/	6229	Advanced
11	Historiography/	4068	Advanced
12	2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11	3177767	Advanced
13	1 and 12	943	Advanced
14	radioactiv*.mp.	122678	Advanced
15	((natural adj2 (radiation or "radioactive material")) or tenorm or residue or remainder or leftover or waste or oil or gas or water or phosphate* or fuel* or geothermal or building* or "flying ash" or mining or mine or "NORM industries" or "building material*" or "alum shale" or (environment* adj1 remediation)).tw.	1766815	Advanced
16	Mining/ or Coal Mining/	17319	Advanced
17	Radioactive Waste/	3027	Advanced
18	natural gas/ or fuel oils/	2258	Advanced
19	Phosphates/	63173	Advanced
20	Geothermal Energy/	40	Advanced
21	"Environmental Restoration and Remediation"/	8437	Advanced
22	Background Radiation/	1425	Advanced
23	15 or 16 or 17 or 18 or 19 or 20 or 21 or 22	1805979	Advanced
24	14 and 23	20813	Advanced
25	12 and 24	1225	Advanced

SEARCH2

Database: **Web of Science**
Date: **23.11.2020**
Search result: **328**

AB=(radioactiv*) AND AB=((natural NEAR/1 (radiation OR "radioactive material")) OR tenorm OR residue OR remainder OR leftover OR waste OR oil OR gas OR water OR phosphate* OR

fuel* OR geothermal OR building* OR "flying ash" OR mining OR mine OR "NORM industries" OR "building material*" OR "alum shale" OR (environment* NEAR/0 remediation)) AND AB=(survey* OR experiment*) AND AB=(public* OR citizen* OR participant* OR respondent* OR resident* OR person* OR stakeholder*)

Database: **Scopus**
Date: **23.11.2020**
Search result: **1574**

TITLE-ABS-KEY(radioactiv*) AND TITLE-ABS-KEY((natural W/1 (radiation OR "radioactive material")) OR tenorm OR residue OR remainder OR leftover OR waste OR oil OR gas OR water OR phosphate* OR fuel* OR geothermal OR building* OR "flying ash" OR mining OR mine OR "NORM industries" OR "building material*" OR "alum shale" OR (environment* W/0 remediation)) AND TITLE-ABS-KEY(survey* OR experiment*) AND TITLE-ABS-KEY(public* OR citizen* OR participant* OR respondent* OR resident* OR person* OR stakeholder*)

Database: **Medline**
Date: **23.11.2020**
Search result: **297**

#	Searches	Results	Types
1	radioactiv*.mp.	122678	Advanced
2	((natural adj2 (radiation or "radioactive material")) or tenorm or residue or remainder or leftover or waste or oil or gas or water or phosphate* or fuel* or geothermal or building* or "flying ash" or mining or mine or "NORM industries" or "building material*" or "alum shale" or (environment* adj1 remediation)).tw.	1766815	Advanced
3	Mining/ or Coal Mining/	17319	Advanced
4	Radioactive Waste/	3027	Advanced
5	natural gas/ or fuel oils/	2258	Advanced
6	Phosphates/	63173	Advanced
7	Geothermal Energy/	40	Advanced
8	"Environmental Restoration and Remediation"/	8437	Advanced
9	Background Radiation/	1425	Advanced
10	2 or 3 or 4 or 5 or 6 or 7 or 8 or 9	1805979	Advanced
11	1 and 10	20813	Advanced
12	"Surveys and Questionnaires"/	475182	Advanced
13	(survey* or experiment*).tw.	2731389	Advanced
14	12 or 13	3055986	Advanced
15	(public* or citizen* or participant* or respondent* or resident* or person* or stakeholder*).tw.	2161732	Advanced
16	11 and 14 and 15	297	Advanced

SEARCH3

Database: **Web of Science**
Date: **23.11.2020**
Search result: **1447**

AB=(radon) AND AB=(((field OR case OR comparative OR cohort OR archival) NEAR/2 stud*) OR ((network OR content OR sentiment OR meta OR framework OR media OR discourse OR morphological OR text* OR conversation OR narrative) NEAR/2 analysis) OR ((systematic OR meta) NEAR/0 review) OR ((mixed OR mental OR mixed OR delphi OR q OR economic) NEAR/2 method*) OR "delphi techniq*" OR "focus group*" OR "repertory grid" OR "analytic induction" OR "life history*" OR historiography OR "socio mapping" OR "feeling thermometer" OR "cybermethod*" OR "participatory action" OR bibliograph* OR questionnaire* OR "secondary data" OR "e-research" OR "memory work" OR interview* OR observation* OR ethnography OR phenomenolog* OR RCT OR "randomized controlled trial*" OR workshop OR "public opinion" OR panel* OR omnibus OR poll OR triangulation OR hermeneutic)

Database: **Scopus**
Date: **23.11.2020**
Search result: **3456**

TITLE-ABS-KEY (*radon*) AND TITLE-ABS-KEY (((*field* OR *case* OR *comparative* OR *cohort* OR *archival*) W/2 *stud**) OR ((*network* OR *content* OR *sentiment* OR *meta* OR *framework* OR *media* OR *discourse* OR *morphological* OR *text** OR *conversation* OR *narrative*) W/2 *analysis*) OR ((*systematic* OR *meta*) W/2 *review*) OR ((*mixed* OR *mental* OR *mixed* OR *delphi* OR *q* OR *economic*) W/2 *method**) OR *"delphi techniq*"* OR *"focus group*"* OR *"repertory grid"* OR *"analytic induction"* OR *"life history*"* OR *historiography* OR *"socio mapping"* OR *"feeling thermometer"* OR *"cybermethod*"* OR *"participatory action"* OR *bibliograph** OR *questionnaire** OR *"secondary data"* OR *"e-research"* OR *"memory work"* OR *interview** OR *observation** OR *ethnography* OR *phenomenolog** OR *rct* OR *"randomized controlled trial*"* OR *workshop* OR *"public opinion"* OR *panel** OR *omnibus* OR *poll* OR *triangulation* OR *hermeneutic*)

Database: **Medline**
Date: **23.11.2020**
Search result: **943**

#	Searches	Results	Type
1	Radon/ or radon.mp.	8133	Advanced
2	(((field or case or comparative or cohort or archival) adj2 stud*) or ((network or content or sentiment or meta or framework or media or discourse or morphological or text* or conversation or narrative) adj2 analysis) or ((systematic or meta) adj2 review) or ((mixed or mental or mixed or delphi or q or economic) adj2 method*) or "delphi techniq*" or "focus group*" or "repertory grid" or "analytic induction" or "life history*" or historiography or "socio mapping" or "feeling thermometer" or "cybermethod*" or "participatory action" or bibliograph* or questionnaire* or "secondary data" or "e-research" or "memory work" or interview* or observation* or ethnography or phenomenolog* or RCT or "randomized controlled trial*" or workshop or "public opinion" or panel* or omnibus or poll or triangulation or hermeneutic).tw.	2776440	Advanced

3	Public Opinion/	18776	Advanced
4	"Surveys and Questionnaires"/	475182	Advanced
5	Interview/	29398	Advanced
6	Cohort Studies/	272356	Advanced
7	Focus Groups/	30791	Advanced
8	Observational Study/	88323	Advanced
9	"Systematic Review"/	139485	Advanced
10	Delphi Technique/	6229	Advanced
11	Historiography/	4068	Advanced
12	2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11	3177767	Advanced
13	1 and 12	943	Advanced

SEARCH 4

Database: **Web of Science**
Date: **23.11.2020**
Search result: **426**

AB=(radon) AND AB=(survey* OR experiment*) AND AB=(public* OR citizen* OR participant* OR respondent* OR resident* OR person* OR stakeholder*)

Database: **Scopus**
Date: **23.11.2020**
Search results: 909

TITLE-ABS-KEY (*radon*) AND TITLE-ABS-KEY (*survey** OR *experiment**) AND TITLE-ABS-KEY (*public** OR *citizen** OR *participant** OR *respondent** OR *resident** OR *person** OR *stakeholder**)

Database: **Medline**
Date: **23.11.2020**
Search result: **327**

#	Searches	Results	Type
1	Radon/ or radon.mp.	8133	Advanced
2	"Surveys and Questionnaires"/	475182	Advanced
3	(survey* or experiment*).tw.	2731389	Advanced
4	2 or 3	3055986	Advanced
5	(public* or citizen* or participant* or respondent* or resident* or person* or stakeholder*).tw.	2161732	Advanced
6	1 and 4 and 5	327	Advanced

SEARCH 5

Database: **Sociological abstracts**
Date: **24.11.2020**
Search: Radon (114) NORM (134) - only journal articles (without method words)

Appendix B. A list of articles included in the systematic review

Reference	Topic	Geographical setting	Study design
(Adams, Dewey, & Schur, 1993)	Radon	Regional	Quantitative
(Alsop & Watts, 1997)	Radon	Local	Qualitative
(Alsop, 2001)	NORM	Local	Qualitative
(Baldwin, Frank, & Fielding, 1998)	Radon	National	Quantitative
(Bostrom et al., 1992)	Radon	Local	Qualitative
(Bostrom et al., 1994)	Radon	Local	Mixed
(Burger et al., 1997)	Radon	Local	Quantitative
(Burger et al., 2000)	Radon	Regional	Quantitative
(Burger, 1998)	Radon	Regional	Quantitative
(Butler et al., 2017)	Radon	Regional	Quantitative
(Carlo, Lee, Sund, & Pettygrove, 1992)	Radon	National	Quantitative
(CDC, 1999)	Radon	National	Quantitative
(Nursan et al., 2014)	Radon	Local	Quantitative
(Nursan et al., 2011)	Radon	Local	Quantitative
Clifford	Radon	Local	Quantitative
(Coleman, 1993)	Radon	Regional	Quantitative
(Coppola et al., 2018)	Radon	Local	Quantitative
(Cothern, 1990)	Radon	National	Qualitative
(Cronin et al., 2020)	Radon	Local	Quantitative
(deLemos et al., 2009)	NORM	Local	Quantitative
(Denman, Phillips, Tornberg, & Groves-Kirkby, 2005)	Radon	Local	Quantitative
(Denman et al., 2009)	Radon	Local	Quantitative
(Denu et al., 2019)	Radon	Regional	Quantitative
(Desvousges et al., 1992)	Radon	Local	Quantitative
(DiPofi et al., 2001)	Radon	Regional	Qualitative
(Dowdall et al., 2016)	Radon	National	Quantitative
(Dragojevic et al., 2014)	Radon	Regional	Quantitative
(Duckworth et al., 2002)	Radon	Local	Quantitative
(Eheman et al., 1996)	Radon	National	Quantitative
(B. E. Erickson, 2007c)	Radon	Regional	Mixed
(Evans et al., 2015)	Both	Regional	Quantitative
(Evdokimoff & Ozonoff, 1992)	Radon	Local	Quantitative
(D. L. Feldman & Hanahan, 1996)	NORM	Local	Quantitative
(Ferng & Lawson, 1996)	Radon	Local	Quantitative
(Field, Kross, & Vust, 1993)	Radon	Regional	Quantitative
(Ford & Eheman, 1997)	Radon	National	Quantitative
(Gagnon et al., 2016)	Radon	Regional	Quantitative
(Gleason et al., 2020)	Radon	Regional	Quantitative
(Golding et al., 1991)	Radon	Local	Mixed
(Groppi, 2018)	Radon	Regional	Qualitative
(Groves-Kirkby et al., 2014)	Radon	Local	Quantitative
(Hahn, Rayens, Kercsmar, Adkins, et al., 2014)	Radon	National	Quantitative
(Hahn, Rayens, Kercsmar, Robertson, et al., 2014)	Radon	Regional	Quantitative
(Hahn et al., 2019)	Radon	Regional	Quantitative
(Halpern & Warner, 1994)	Radon	National	Quantitative
(Hamilton, 2003)	NORM	Local	Qualitative
(Hampson, Andrews, Barckley, et al., 2000)	Radon	Regional	Quantitative

(Hampson, Andrews, Lee, et al., 2000)	Radon	Regional	Quantitative
(Hampson et al., 2003)	Radon	Local	Quantitative
(Hampson et al., 1998)	Radon	Local	Mixed
(Hampson et al., 2006)	Radon	Regional	Quantitative
(Hazar et al., 2014)	Radon	Local	Quantitative
(Hill et al., 2006)	Radon	Regional	Quantitative
(Himes, Parrott, & Lovingood, 1996)	Radon	Local	Quantitative
(Huntington-Moskos, Rayens, Wiggins, & Hahn, 2016)	Radon	Regional	Quantitative
(Immé et al., 2013)	Radon	Regional	Qualitative
(Jansson, Thol, er, & Axelson, 1989)	Radon	Local	Quantitative
(Johansson et al., 2007)	Radon	National	Qualitative
(B. B. Johnson, 2017)	Radon	Regional	Qualitative
(F. R. Johnson & Luken, 1987)	Radon	Regional	Quantitative
(Jones et al., 2019)	Radon	National	Quantitative
(Kara, Saricam, & Nurlu, 2011)	NORM	Local	Quantitative
(Keller, 2011)	Radon	Local	Quantitative
(Keller, Siegrist, & Visschers, 2009)	Radon	Local	Quantitative
(Kendall et al., 2016)	Radon	National	Quantitative
(Kennedy et al., 1991)	Radon	Local	Quantitative
(Khan et al., 2018)	Radon	Regional	Quantitative
(Khan & Chreim, 2019)	Radon	Regional	Qualitative
(Kilpatrick et al., 2002)	Radon	Regional	Quantitative
(Kojo & Kurttio, 2020)	Radon	Local	Quantitative
(König et al., 2014)	NORM	Local	Qualitative
(Laflamme & erslice, 2004)	Radon	Regional	Quantitative
(Larsson, 2015)	Radon	Local	Quantitative
(Larsson, Hill, Odom-Maryon, & Yu, 2009)	Radon	National	Quantitative
(Lawson & Ferng, 1997)	Radon	Local	Quantitative
(M. E. Lee et al., 1999)	Radon	National	Mixed
(G.-W. Lee et al., 2017)	Radon	National	Quantitative
(Levy et al., 2015)	Radon	Local	Quantitative
(Loffredo et al., 2020)	Radon	Local	Quantitative
(Losee et al., 2020)	Radon	National	Quantitative
(Macher & Hayward, 1991)	Radon	Regional	Qualitative
(Mainous & Hagen, 1993)	Radon	Regional	Quantitative
(Makedonska, Djounova, & Ivanova, 2018)	Radon	National	Quantitative
(Mancl, Heimlich, Fentiman, & Christensen, 1994)	Both	Regional	Quantitative
(Mardis et al., 1988)	Radon	National	Mixed
(Martin et al., 2020)	Radon	Regional	Mixed
(Mazur & Hall, 1990)	Radon	Local	Quantitative
(Mazur, 1987)	Radon	National	Mixed
(Momin et al., 2018)	Radon	Regional	Qualitative
(Murphy et al., 2019)	Radon	Regional	Mixed
(Neri, McNaughton, Momin, Puckett, & Gallaway, 2018)	Radon	Regional	Quantitative
(Nicotera, Nobile, Bianco, & Pavia, 2016)	Radon	Regional	Quantitative
(Nissen et al., 2012)	Radon	Local	Quantitative
(Nwako & Cahill, 2020)	Radon	Regional	Quantitative
(Park et al., 2001)	Radon	Local	Quantitative
(Perko, 2014)	Radon	National	Mixed

(Perko et al., 2012)	Radon	International	Quantitative
(Peterson & Howland, 1996)	Radon	Local	Quantitative
(Petrescu & Petrescu-Mag, 2017)	Radon	Regional	Quantitative
(Petrescu et al., 2019)	NORM	Local	Mixed
(Poortinga et al., 2008)	Radon	National	Quantitative
(Poortinga et al., 2011)	Radon	Local	Quantitative
(Prochaska et al., 1994)	Radon	Local	Quantitative
(Pugliese et al., 2019)	Both	Regional	Qualitative
(Rafique, Jabeen, & Shahzad, 2008)	Radon	Regional	Quantitative
(Rahman et al., 2006)	Radon	Local	Quantitative
(Rajagopal & Tobin, 1990)	NORM	Regional	Quantitative
(Rickenbacker et al., 2020)	Radon	Local	Quantitative
(Riesenfeld et al., 2007)	Radon	Regional	Quantitative
(Rinker et al., 2013)	Radon	Local	Quantitative
(Rothman & Lichter, 2001)	Radon	National	Quantitative
(D. Ryan & Kelleher, 1998)	Radon	Local	Mixed
(Sanborn et al., 2019)	Radon	Regional	Quantitative
(Sandman, Weinstein, & Klotz, 1987)	Radon	Regional	Quantitative
(Sandman et al., 1994)	Radon	Local	Quantitative
(Scivyer et al., 2005)	Radon	Local	Qualitative
(Siegrist, Cvetkovich, & Gutscher, 2001)	Radon	Local	Quantitative
(Siza, Morrison, Harris, Hatch, & Tyler, 2018)	Radon	Local	Quantitative
(Sjöberg, Peterson, Fromm, Boholm, & Hanson, 2005),	Both	National	Quantitative
(Smith et al., 1988)	Radon	Regional	Quantitative
(Smith et al., 1995)	Radon	Regional	Quantitative
(Smith, Desvousges, Johnson, & Fisher, 1990)	Radon	Regional	Quantitative
(Spiegel & Krewski, 2002)	Radon	Local	Quantitative
(Tahir & Alaamer, 2008)	Radon	Local	Quantitative
(Torres et al., 2017b)	NORM	Regional	Quantitative
(Torres et al., 2017a)	NORM	Regional	Quantitative
(Wang, Ju, Stark, & Teresi, 2000)	Radon	Regional	Quantitative
(Wang, Ju, Stark, & Teresi, 1999)	Radon	Regional	Quantitative
(Weinstein & Sandman, 1992b)	Radon	Regional	Quantitative
(Weinstein et al., 1989)	Radon	Regional	Mixed
(Weinstein et al., 1990)	Radon	Local	Quantitative
(Weinstein, Sandman, & Roberts, 1991)	Radon	Regional	Quantitative
(Weinstein & Sandman, 1992a)	Radon	Regional	Quantitative
(Weinstein, Klotz, & Sandman, 1988)	Radon	Regional	Quantitative
(Weinstein & Lyon, 1999)	Radon	Local	Quantitative
(Weinstein et al., 1998)	Radon	Local	Quantitative
(Weinstein, Roberts, & Pflugh, 1992)	Radon	Regional	Quantitative
(Whittaker, 1988)	NORM	Local	Qualitative
(Witte et al., 1998)	Radon	Local	Qualitative
(Zierold & Sears, 2015)	NORM	Local	Mixed
(Zierold & Sears, 2014)	NORM	Local	Mixed
(Zierold et al., 2015)	NORM	Local	Mixed

Appendix C. Data extraction form

Dear all, welcome to the standardized form for the WP6 method review.

Please record any missing information as 'not described', to make it clear that the information was not found in the study report(s), not that you forgot to extract it.

General information

Name of person extracting data	Yevgeniya Melisa Tanja Peter Nadja Robbe David Catrinel Mandy Alison Someone else:
Reference citation (year)	
Reference citation (authors) (write the surname of the first author up front)	
Reference citation (title)	
Aim of the study (based on abstract and if not found there, then from the full text)	

Participants

Population description - detailed description of the group from which participants are drawn (e.g. age/gender group, occupational group etc.)	
Population description – general categorization (only select multiple options if there are multiple groups described)	Public/Citizens/Residents Property owners (e.g. house) Tenants (rent property) Individuals/families that request radon Workers in NORM industries (e.g. miners, oil, phosphate, ..) Parents or guardians

	Students or school children Policymakers Experts Other:
Setting (choose and specify)	Local (village, city, municipality) Region (e.g. 'Flanders', state in the USA) National (on the federal/country level) International (several countries)
Was the method(ology) described at least somewhere in the text? (if not and you are unable to fill out any of the questions that follow this one, then please email us)	Yes No
Method of recruitment of participants (sampling) as describes by author(s)	Random Sample (simple/stratified/ cluster) Systematic Sample (e.g. random walk) Convenience Sample Quota Sample Snowball Sample No information If the author(s) did not use any of these words then please describe the sampling method:
Mode of recruitment of participants (e.g. contacted people via phone, email, letter, …)	Via phone Via email Via letter (post) Via newspaper advertisement Via social media advertisement Face-to-face recruitment Survey/leaflet/… left in a public setting Other:

Sample size (how many people successfully participated)	
Response rate (how many people were contacted and how many participated) (if specified)	
Did the author(s) state that the sample is representative?	Yes, they stated the sample is representative No, they stated the sample is unrepresentative No, they did not state anything (no information)

Methods

Design (if you are unsure please email us so we can help you)	Quantitative Description Quantitative Explanation Qualitative (Description or Explanation) Mixed Methods

Display this Question: If Design: Quantitative Description or Quantitative Explanation or Mixed Methods Is Selected **Dependent variable(s) conceptualization** (give the name/definition of the primary outcome measured and where relevant also the secondary outcomes)	
Display this Question: If Design: idem **Dependent variable(s) indicators** (describe the questions, scales or tools used to measure the outcomes e.g. 'hazard X, Y and Z are measured on a 7 point Likert scale from not risky-very risky')	
Display this Question: If Design: idem **Independent variable(s) conceptualization** (give the name/definition of the predictor variable e.g. home type/age/..)	

Display this Question: If Design: idem **Independent variable(s) indicators** (describe the questions, scales or tools used to measure the predictors) (You do not have to specify all indicators if there are more than 10 independent variables)	
Display this Question: If Design: idem **Were formal hypotheses formulated?**	Yes No

Display this Question: If Design: Quantitative Description Is Selected **Type of Quantitative Description**	Overview study focusing on frequency and cross tables (e.g. percentage of people that are aware of radon) Detailed study of contextual measure(s) (e.g. territorial differences or radon exposure) Other, please specify:
Display this Question: If Design: Quantitative Explanation Is Selected **Type of Quantitative Explanation**	Multivariate regression Experimental (testing) Other, please specify:

Which method was used?	Observations (naturalistic, controlled, participant) Participatory study Survey(s) Interview(s) Focus Group(s) Experiment(s) Mixed Methods (combination of some of the above/other) Other, please specify:

Display this Question: *If* Method: Experiment(s) Is Selected **What was the size of the experimental groups and how many groups were there?** (e.g. 3 groups with 15 people per group)	
Display this Question: *If* Method: Focus Group(s) Is Selected **What was the size of the focus groups and how many groups were there?** (e.g. 3 groups with 15 people per group)	
Duration of participation – if applicable (e.g. how long was the interview)	

Measurement instruments related to radon/norm

Was radon explicitly covered in the study?	Yes No
Display this Question: *If* Radon explicitly covered in the study? : Yes Is Selected **Specific study or part of a broader study?**	Specific focus–multiple indicators Part of broader study
Display this Question: *If Specific study or part of broader study? : Part of broader study Is Selected* **What is the general focus of the broad study?** (e.g. radiation risks, environment, …)	
Display this Question: *If Specific study or part of broader study? : Part of broader study Is Selected* **How many questions in the study were about radon?**	

Was NORM explicitly covered in the study?	Yes No
Display this Question: *If* NORM explicitly covered in the study? : Yes Is Selected **Specific study or part of a broader study?**	Specific focus–multiple indicators Part of broader study
Display this Question: *If Specific study or part of broader study? : Part of broader study Is Selected* **What is the general focus of the broad study?** (e.g. radiation risks, environment, …)	
Display this Question: *If Specific study or part of broader study? : Part of broader study Is Selected* **How many questions in the study were about NORM?**	

Did the author(s) to the reliability of the measurement instruments? (see glossary for potential ways this can be mentioned)	Yes, authors did a reliability analysis themselves (on self-constructed or pre-existing tools) No, but authors mention that they used pre-existing tools (without doing a reliability analysis themselves) No
Did the author(s) to the validity of the measurement instruments? (see glossary for potential ways this can be mentioned)	Yes, authors did a validity check themselves (on self-constructed or pre-existing tools) No, but authors mention that they used pre-existing tools (without doing a validity check themselves) No

Dataset

When was the data collected? (e.g. "surveys were collected in April 2014")	
What kind of dataset was used?	Pre-existing Self-constructed
Was the data pulled from one dataset or from multiple datasets?	Single dataset Multiple datasets
Was a database/questionnaire/ (interview) transcript/protocol provided in its entirety ? (as an electronic appendix or as a link)	Yes, database Yes, questionnaire Yes, transcript Yes, research protocol No, but author(s) state that data and/or materials are available upon (reasonable) request No
Display this Question: *If Was a database/questionnaire/…?: Yes, database Is Selected* **What is the name of the database?** (e.g. Euratom, Eurobarometer, …)	

Results

Which data analysis software was used? (if communicated by the author) (note: software! not the type of analysis)	
What were the main conclusions? (based on the abstract and if not found there then from the full text)	

Ethics

Who commissioned/funded the study and which institutions were involved?	
Possible conflicts of interest? (as defined by the authors)	

Was ethical approval obtained for the study?	Yes No (not obtained or simply not mentioned)
Information related to ethical approval (even if you are not sure e.g. 'institutional review board approval was obtained' – we will check this)	
How was privacy handled in general? (e.g. anonymity of respondents, how the data was stored etc.)	

Comments

Use this box for any important or interesting additions/observations	

Appendix D. Glossary for data extraction

Glossary of Terms

Aim of the study	Sentence(s) that express an intention or aspiration of the research study; it summarizes what the researchers wanted to do. e.g. ".. to explore perception of radon risk and examine the factors that enable and hinder the adoption of preventive measures" "The objective was to measure radon knowledge…" ".. to investigate the association between …"
Broader study	The study was about a more general topic (e.g. radiation risks, environment, …) but there is at least one section/question about radon/norm.
Conceptualization	Term (definition) that represents the idea that you wish to study or represents collections of seemingly related observations and/or experiences.
Convenience Sampling	Selecting participants from a group of people that are conveniently available and willing to participate, with no further requirements. e.g. Standing in a mall and asking people that walk by questions, a Facebook poll, …
Data Analysis Software	The software and applications that are used to clean, transform and model data. e.g. SPSS, Stata, Nvivo, ArcGIS, …
Dependent Variable	The primary outcome related to Radon/NORM that is being measured in the study.
Duration of Participation	The length of the interview/focus group/estimate time of survey/.. (if mentioned)
Focus Group	A way of collecting data by organizing a facilitated discussion among deliberately selected people who then talk about particular topic(s).
Independent Variable	The variable whose change is not affected by any other variable in the study, but that changes on its own or can be manipulated (changed) by the researcher. A change in the independent variable results in a change in the dependent variable. (only independent variables which are used in the analysis related to radon/norm should be reported)
Indicator(s)	The metrics used to measure (presence/absence) of the concept being studied. e.g. if the variable is 'radon knowledge' then an indicator could be 'the average achievement scores on a radon knowledge test'
Mixed Methods	A type of research in which elements of quantitative and qualitative research approaches are combined. e.g. surveying participants (quantitative part) and also conducting focus groups (qualitative part)
Mode of recruitment of participants	The means by which the researcher(s) establish contact with the potential candidates. e.g. by calling them, sending an email, …
Multivariate (Multiple) Regression	A technique used to measure the degree at which more than one independent variable and more than one dependent variable are linearly related.
Observations	Is a way of collecting data through observing. The researchers goes to a setting and takes notes and/or records what (s)he sees.

Participatory study	The participants themselves are the ones who control the research agenda, process, actions, analyze and/or reflect. (e.g. stakeholder meetings, action research, ..)
Population	The aggregate of items or events (people, objects, actions, ..) grouped together by a common feature, which is of interest for the study. e.g. all Belgians, all workers in a specific mine (for NORM)
Qualitative/Quantitative Description	Studies which aim to describe a population, situation or phenomenon; list the attributes, assign into classes or categories, makes statements about the whole by observing a part etc. E.g. comparing radon exposure between two cities
Qualitative/Quantitative Explanation	Studies which aim to point to the causes of events, identify general causal effects and reveal the causal mechanisms that produce them. E.g. examining the effect of a testing campaign on people's willingness to test their house (If explanation is a part of the article (even if minor), it should be categorized as "explanation" not "description")
Qualitative/Quantitative Research	Qualitative: Research that collects and analyzes non-numerical data (e.g. text, video or audio) Quantitative: Research that collects numerical data and that uses mathematical based methods (statistics) for analysis
Quota Sampling	Selecting participants in proportion to some characteristic or trait of a population. e.g. your population consists of 45% female and 55% male and you want to interview 1000 people. Then you will only interview 450 female respondents.
Random Sampling	Participants are chosen randomly and entirely by chance from a complete frame/list of all eligible individuals. Each individual has the same probability of being chosen. e.g. from a list of all SCK CEN employees, 100 are chosen at random
Reliability Analysis	There was mention of (for example): - the words "reliability analysis/test/check/.." -Internal consistency: e.g., Split half reliability ;Kuder-Richardson; Cronbach's alpha -Temporal stability: e.g., test-retest reliability, intraclass coefficient ICC -Parallel forms: alternate forms reliability Agreement: inter-rater reliability (e.g., % agreement, phi, kappa, kendall tau, ICC) - Generalizability theory: generalisability coefficient - …
Response rate	How many people were contacted (the "initial sample") and the number of people that participated (note: do NOT divide the participants by the number of contacted people. We can do this later)
Sampling	Taking a small selection from a larger group in order to draw inferences about that larger group.

Sample size	The amount of people whose data was used in the analysis. (Note: if there are only a few questions on radon/norm within a larger/broader study, then write down the amount of people that answered those specific questions, if this is specified) (note: for different analyses the amount of included people can vary, but write the highest number and perhaps write a comment at the end of the Qualtrics)
Setting	Information about the location in which the study is conducted and/or the participants live. - Local = village, city, municipality, province, .. - Regional = regions (or states in the US) - National = federal/country level - International = multiple countries or supra-national (= above the national level)
Snowball Sampling	Selecting participants on the recommendations of a previous research subject. As a snowball gathers more snow when rolling down a hill –so extra subjects are 'collected' and added to the sample.
Survey	Is a way of collecting data by asking people questions through a questionnaire (online or offline).
Systematic Sampling	Selecting participants according to a random starting point but with a fixed, periodic interval. e.g. you want a sample of 8 houses from a street of 120. The random starting point is 11 and every 15th house is chosen. So, houses 11, 26, 41, … are selected.
Validity analysis	There was mention of (for example): - the words "validity analysis/test/check/.." -Construct validity: does scale measure stuff it is meant to measure -Content validity: does the scale cover all relevant parts of construct -Criterion validity -Convergent validity: does scale relate to stuff it should correlate with -Predictive validity: does scale predict stuff in future that it should predict -Factorial validity: internal structure (EFA, CFA) - ..

Appendix E. Complementary literature reviews from other studies

I. Methods in Radon-related Citizen Science projects

I.I Introduction

Citizen science is increasingly viewed as an umbrella term which describes the different ways in which citizens are involved in scientific activities (ECSA, 2015; Hecker et al., 2018). Citizen science initiatives are recognised for their scientific, societal and policy value related to environmental issues. They have been largely conducted in the field of environmental sciences, but not so widely spread in the field of radioactivity measurements. Citizen science initiatives measuring radioactivity in the environment are not new. The first citizen science initiatives recorded in this field date back to the Three Mile Island Accident (Angelique & Culley, 2014; Culley & Angelique, 2010; Gricar & Baratta, 1983; Walsh, 1981). The largest international online citizen science project in this field is the on-going Safecast, which was formed in response to lack of accurate and trustworthy radiation information after the earthquake and tsunami which struck eastern Japan on March 11, 2011, and the subsequent meltdown of the Fukushima Daiichi Nuclear Power Plant. Safecast was initiated by citizens to monitor, collect and openly share information on environmental radiation – growing quickly in size, scope and geographical reach (Brown, Franken, Bonner, Dolezal, & Moross, 2016). Ten years after, citizen radiation measuring organizations continue to monitor the contamination caused by the Fukushima nuclear accident.

The definition and delimitation of what citizen science is and what it is not has been subject to different interpretations. It has been generally acknowledged that citizen science may take different forms, include various kinds of activities and levels of engagement (see Eitzel & Cappadonna, 2020; Haklay, 2013; Kasperowski, 2017; Wiggins & Crowston, 2011). Some practitioners of citizen science defend the utilisation of citizen science as a recognised scientific practice, method, tool or form of research collaboration (e.g. Wiggins and Crowston, 2011; Follet and Strezov, 2015). Kasperwoski et al. (2017) identify "*three main forms of citizen science: a) citizen science as a research method aiming for scientific output; b) citizen science as public engagement, aiming to establish legitimacy for science and science policy in society and c) citizen science as civil mobilisation, aiming for legal or political influence in relation to specific issues*". This classification echoes the five models of Shirk et al. (2012) defining the interaction with scientists through public participation in scientific research depending on the level of involvement and control of participants over the different steps: a) contractual projects; b) contributory projects; c) collaborative projects; d) co-created projects and d) collegial contributions. Similarly, Haklay (2013) proposes the four levels of citizen science activities from level 1 "crowdsourcing", level 2 "distributed intelligence", level 3 "participatory science" to level 4 "extreme citizen science".

Although citizen science projects have been largely conducted in the field of environmental sciences, information is still lacking regarding its current and potential contribution to radon research. As part of Task 6.3 in RadoNorm, we aim to map past and on-going citizen science initiatives in the field of radon testing and radon mitigation as well as to analyse the potential contribution of citizen science to radon research. We consider citizen science initiatives in a broader sense to include radon projects which might not necessarily be called "citizen science" as such but have the potential to mobilise citizens to test themselves for radon in their homes, workplaces and schools. We have not considered projects which are purely educational, are basically awareness campaigns and therefore, have no research goal or research question.

I.I Methodological approach

In order to identify what kind of methods have been applied in citizen science projects, a systematic review of internet pages and scientific literature was conducted (September-December, 2020) as well

as expert consultation to help us identify and assess citizen science initiatives on radon (September 2020-February 2021). Overall, we identified, reviewed and analysed in depth nine citizen science initiatives in five countries. Characteristics and the ten principles of citizen science (ECSA, 2015, 2020) were used to develop indicators and systematically evaluate ongoing and planned citizen science initiatives in order to contribute to the national radon research.

Drawing on internet pages and scientific literature of citizen science on the field of radon, we examined the methods documented for sampling and involving citizens in data collection. The sample of projects we selected has some limitations: we reviewed past and currently active citizen science projects which had a website in English or are reported in papers. Additional projects which are not reported in English could not be identified.

I.III Methods applied in citizen science projects related to radon

The methods used by the researchers or the authorities launching citizen science initiatives consist mainly of comprehensive (online) surveys to elicit basic information, such as home construction year, build type, foundation type, and floor and room of deployment of the radon detector, among others, (e.g. F. K. Stanley et al., 2017; Yazzie, Davis, Seixas, & Yost, 2020) and behavioural information (e.g. F. K. T. Stanley et al., 2019). Visual observations were also used in some cases (Yazzie et al., 2020). The sample for the survey is based on the voluntary participation of homeowners or renters who might be interested in measuring radon in their homes. Public outreach may be achieved through print and online media (website and social media) as well as television and radio in a targeted or untargeted manner, depending on the country and the initiative.

In the specific case of involving school children in data collection through the citizen science approach (see Tsapalov et al., 2020), the dwellings covered corresponded to the random sampling principle and the distribution of measurement points is in proportion to the population density. In Italy, students do not only conducted measurements in their respective schools, but also in their houses or different places like caves, archaeological sites, etc, motivated by their curiosity (Groppi, 2018).

Another method found to be used by researchers to measure radon is community based participatory research in vulnerable populations in Massachusetts (Downs et al., 2010). For this, academic researchers and community-based groups jointly conceived, designed, initiated, run the project and evaluated the results. This partnership researchers- community engaged with residents who participated in the participatory testing and reporting of indoor pollution, being radon in basement air one of the household toxics tested. Surveys conducted by the partnership and participatory observation by the academic researchers were used to assess overall experience and lessons learned. Similar to the approach in Massachusetts, the RADAR (Residents Acting to Detect and Alleviate Radon) study will engage residents of rural Kentucky communities and train them to be “citizen scientists”[3].

In five of the nine citizen science projects analysed, there are principles and guidelines on legal and ethical issues. Institutional review, ethics boards or governmental authorities need to approve the work to be conducted. A reflection on research ethics and citizen science on radon testing is done by Oberle, Page, Stanley, and Goodarzi (2019) taking the experience of Evict Radon in Canada as an example. Prior to the initiation of any research activities involving volunteers, an application form and an informed

[3] We found an open call for a planned citizen science project in Kentucky. The study will identify geological and atmospheric conditions that increase radon intrusion into homes, translate this knowledge into increased residential awareness of lung cancer risk, facilitate home radon testing, and report back and increase access to affordable and adequate radon mitigation, by engaging residents of rural Kentucky communities and training them to be “citizen scientists”. https://uknow.uky.edu/research/researchers-awarded-26-million-engage-citizen-scientists-reduce-radon-exposure-rural-areas (last accessed 15 February 2021)

consent form are submitted and participants are educated in the correct test deployment methods through communication with professionals. In all cases, the personal data of participants is anonymised.

I.IV Concluding remarks

The citizen science approach has been successfully used for collecting data from the public and assist scientists in their research endeavours. Citizen science can therefore be considered a method in itself to engage the public as co-researchers in collecting data or even, in some cases, to co-design the research question, the method, interpret and disseminated the results. Our analysis confirms that citizen science is often considered a form of research collaboration which has potential benefits for both researchers and citizens: it raises awareness on radon matters and can help to achieve not only scientific objectives but also educational objectives. As any other research method, using a citizen science approach may pose concerns related to data collection, analysis or interpretation, mostly resulting from having lay citizens conducting measurements (Follett & Strezov, 2015), the discrepancy with regulations and official procedures or the trust on official measurements (Rubio-Iglesias et al., 2020). However, datasets are usually of sufficient quality for future research and the projects can be designed in a way that mitigate against these errors (Follett & Strezov, 2015). Moreover, as demonstrated in the review of citizen science initiatives launched by Environmental Protection Agencies conducted by Rubio-Iglesias et al. (2020) “the potential of citizen science clearly outweighs the concerns”.

It is interesting to note that in the field of radon research, we found out that citizen science initiatives are launched in a top-down manner, exclusively by public authorities and/or researchers. The fact that there is poor public awareness about radon may be an important factor for authorities launching citizen science initiatives, which ultimately seem to go only a bit beyond communication and awareness campaigns. Additionally, the citizen science projects mapped and assessed are so far limited to radon testing and none of them focus on mitigation.

II. Methods in investigating communication interventions

II.I Aim of the review

As part of the RadoNorm subtask 6.2 to develop health communication tools and methods, a systematic review was conducted to investigate mass media communication interventions that focus on reducing indoor radon levels.

In this context, mass media is defined as: “any communication channel used to simultaneously reach a large number of people, including radio, TV, newspapers, magazines, billboards, films, recordings, books, the Internet, and smart media” (Wimmer, 2013, p. 2), this also includes brochures and leaflets. Communication interventions are defined as health promotion programs to change behavioural factors related to health, and its proximal determinants (Bartholomew, 2011).

Although the broader scope of this systematic review was to look at mass media communication interventions as a whole, the focus of this chapter is on how these interventions were evaluated, and how outcomes were measured.

II.II Short description of methodological approach

As proposed by the Cochrane Handbook for Systematic Reviews of Interventions (Higgins, 2020), the systematic review was conducted based on a predefined search protocol. This protocol consisted of a

research question, a search strategy that defined the search terms and the databases, and inclusion and exclusion criteria to review the search results. As for the actual search, the PRISMA-flow was followed (Moher, Liberati, Tetzlaff, & Altman, 2009). The initial search yielded 1732 results. First of all the duplicates were removed, in the next step the digital tool Rayyan was used to evaluate the abstracts (N = 1102) based on the predefined inclusion criteria (Ouzzani et al., 2016). After this stage the remaining results (N = 79) were evaluated based on the full texts, which resulted in a final sample of forty peer-reviewed papers. A second reviewer reviewed 20% of both the abstracts and the full-text in order to avoid any coder bias. The Cohen's kappa was $k_{full\text{-}text} = 0.86$.

II.III Main results

To gain insights in the methods used for evaluating communication interventions, an overview will be given of the different types of evaluations. For the sake of this chapter, the communication interventions (N = 28) mentioned in the selected publications (N = 40) will be discussed.

When looking at the different communication interventions, four types of evaluation can be distinguished. The first one is **formative research** (N = 1), in this case participants evaluated communication materials such as brochures and trinkets in focus groups (Witte et al., 1998). This is the only case where qualitative methods were used.

Lab experiments (N = 8)**,** the second type of evaluation, were used to determine the efficacy of different communication materials. Generally speaking, an experiment with a pre-test, post-test and a random assignment of participants to the intervention condition(s) or comparison condition, is perceived as the strongest design, however also quasi-experimental designs can be used to evaluate the efficacy of an intervention (Bartholomew, 2011; Noar, 2009). As for the interventions in the sample, a lot of different experimental designs were used. Some studies used a pre- and post-measure, had a control group and assigned participants randomly to a condition (Hahn et al., 2019), while others used a post-test only (LaTour & Tanner Jr., 2003) or had an intervention condition only (Kim, Brewster, & Schwartz, 2020).

In the third category, namely the **field experiments** (N = 8), the effectiveness of communication materials is tested in a natural environment, such as cities or communities. In this case, the scientists have less control than in lab experiments, however the external validity in field experiments is higher. Methods used to evaluate field experiments are, for instance, testing different components of interventions in different communities (Desvousges et al., 1992), or a post-test design in one specific community (Hahn, Rayens, Kercsmar, Robertson, et al., 2014).

The final category involves the **implementation studies** (N = 11), where complete communication interventions were carried out, often nationwide. The evaluation of these types of interventions could therefore not rely on an experimental design. Examples of methods that are used to be able to say something about the effectiveness of the communication interventions are measuring the reach (Baechler & Englin, 1991), the order numbers of radon test kits (Long & Fenton, 2011), or measuring the calls for extra information to radon-phone numbers (Burns et al., 1998) and comparing those with the period before the intervention.

Finally, a brief overview will be given of outcome measures used. Outcomes measured occur on two levels, namely performance objectives and change objectives (Bartholomew, 2011). When looking at performance objectives, the results show that both intention and actual behaviour (testing and/or mitigating) are measured, either as a self-reported or an objective measure. Examples of objective measures are the ordering and/or resending of indoor radon test-kits (Nissen et al., 2012). As for the change objectives, a variety of measures were used, of which knowledge, awareness, risk perception and perceived susceptibility were most frequently measured.

II.IV Concluding remarks

When looking at why methodology is important in communication intervention research, it comes down to the process evaluation on the one hand and the evaluation of efficacy or the effectiveness of interventions on the other hand. When communication interventions are not evaluated properly, it is harder to identify whether they were effective, appreciated, reached the right audience and so on (Noar, 2009). A good evaluation and reporting of methods therefore contribute to the knowledge within the field of health promotion and allows the field to improve (Bartholomew, 2011).

To summarize the methodological findings of the systematic review, communication interventions are mostly evaluated by using quantitative methods, and more specifically experiments. Lab experiments, field experiments and implementation studies all have their own limitations and challenges, and a validity trade-off occurs between these levels (Roe & Just, 2009). However, the variety of different methods used (within levels), makes it harder to compare across communication interventions.

It is for that reason that a more systematic approach is recommended in evaluating communication interventions. In the RadoNorm project a lot of attention will be given to designing methods to evaluate communication interventions from the formative stage to field studies. Additionally, guidelines will be formulated to implement and evaluate the communication intervention based on the process and the outcome. Only then will we be able to define the right communication strategies to reach the objectives of convincing people to take action, and contribute to the health promotion research at the same time.

III. Methods in investigating communication interventions related to Radon on Macro, Meso and Micro Level

III.I Introduction

The RadoNorm Work Package 6 (WP6) Task 6.2 has an objective to develop efficient communication interventions, which influence individuals' radon risk behaviours related to performing measurements of indoor radon concentration or applying mitigation actions such as with home renovation. As part of this task, a systematic literature review was conducted to help achieve this objective.

In this context, we defined communication interventions as a communication programme/strategy (e.g., public information campaign) that was intended to change behaviour (e.g., test and/or mitigate a home). Stakeholders are broadly defined as an individual, group or organisation with an interest and/or opportunity to be involved in radon risk management (e.g., contribute, act, influence, receive) in terms of information provision and decision-making (e.g., construction industry, building owners, general public and regional and local authorities) (Turcanu et al., 2020).

Radon issues have to be addressed not only on the individual and interpersonal level, but also on the organisational, community and societal levels (World Health Organization, 2009). As such, we grouped stakeholders into three categories: macro, meso and micro stakeholders. Stakeholders from the macro level are stakeholders from national or international level(s) (e.g., intergovernmental organisations), while stakeholders from the meso level are from the community or organisational level. Stakeholders from the micro level are individuals, such as homeowners or employees.

Within the systematic review, we sought to answer the question "What is the relationship between communication interventions' micro, meso and macro level characteristics and indoor radon testing and/or remediation behaviour?." The following subchapter provides a short description of our methodological approach to answering this systematic review research question. Then, we summarize methodological characteristics of studies included in the systematic review, followed by some concluding

discussion on limitations of the methodology applied in these studies in the context of answering the research question.

III.II Short description of methodological approach

To address our research question, we conducted a systematic review on communication interventions and two radon protective behaviours: indoor radon testing and remediation. The systematic review methodology was aligned where possible with the Cochrane Handbook on Systematic Reviews (Higgins, 2020) and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2009).

The search terms were developed with input from relevant subject matter experts in radon risk mitigation, risk perception, communication and health psychology. The search string was tested and applied to sixteen (16) databases, which were selected to ensure identification of relevant articles across interdisciplinary fields. In retrospect, the number of databases could have been reduced given the number of duplicates (n = 1950). The inclusion criteria were formulated based on the research question and following Cochrane's PICO structure (i.e., Population, Intervention, and Outcome). The decision was made to include studies regardless of baseline measurements or study design, so the "C" comparator was excluded from the eligibility criteria.

The eligible abstracts and full text records were screened based on pre-defined inclusion criteria. To ensure reliability, a second reviewer blind screened 20% of the eligible abstracts and full text records using the same inclusion criteria. The agreement rate for the full text review was 95% and the Cohen's kappa value was 0.88. Any conflicts between the two reviewers were discussed and any unresolved conflicts were brought to a master coder.

Data were extracted from the included full text records using an Excel template. The data extraction template included information from the records related to their research methods, population, intervention and behaviour (indoor radon testing and/or remediation). For the intervention and population, data were extracted related to the stakeholders who were involved in the development and delivery, which includes communication, of the intervention.

III.III Results Related to Methods Applied

In the section below, we will discuss the initial results in terms of research methods used in 34 interventions presently identified in this systematic review phase.

What Research Methods Were Applied?

Full text records included qualitative (n= 1, 3%), quantitative (n= 19, 56%), and mixed methods (n= 14, 41%). The one qualitative (Golding et al., 1991) study used focused groups and interviews with follow-up panels, to obtain descriptive qualitative data about the effectiveness of risk communication. Though there was only one (1) study which used qualitative methods to measure the effectiveness of the intervention, focus groups were used in other studies to gather information about radon-related behaviour and attitudes in order to develop the content of the intervention itself.

Quantitative methods were more commonly found in the included full text records. Self-reported online, in-person and telephone surveys were used both to measure pre- and post- intervention characteristics, behaviour and to obtain socio-demographic data. Descriptive programmes or case studies often used primary or secondary data from surveys or archival sources to quantify the impact of the intervention on indoor radon related behaviour. Several (n=10, 29%) records used experimental methods to test an intervention. These included quasi-experimental and randomised-control trial study designs (Hahn et al., 2019), and could include more than one variation of the intervention. Mixed method studies used a combination of the qualitative and quantitative research methods described above.

How Were Participants Recruited?

A variety of random and non-random sampling methods were found in the included full text records. Selection of a particular sampling methods seemed to be related to the particular study design. In the studies (n= 6) with less than 100 individuals recruited, the studies used quota sampling (n=2), convenience sampling (n=3) and stratified population sampling (n=1). For example, in Hahn et al. (2018) the research team used quota sampling to ensure that at least 50% of the total 47 participants were smokers. Communication interventions involving mass media delivered the intervention to entire target population, which could be at a macro (national) level, as in Long and Fenton (2011) or meso (regional) level as in Devousges et al. (1989).

In addition, some studies macro level stakeholders recruited meso level stakeholders to participate in programmes. For example, the UK Radon programme (Green, Davey, McLaughlin, Simopoulos, & Steinhausler, 2005) recruited Local Authorities to participate in the Radon Programme and engage with individual homeowners. A Finnish study contacted municipal environmental health authorities to assist with information on the schools that should participate in the intervention (Kojo & Kurttio, 2020).

How Were Behaviours Reported?

Methods to measure behaviour, specifically radon testing and remediation, vary slightly between studies. Radon testing behaviours were either (a) self-reported (n= 8), or (b) based on submission of a radon test or report (n = 14), or (c) reported as tested by author but unclear how data was collected (n= 4). Radon remediation behaviours were primarily self-reported (n= 4) efforts to reduce indoor dwelling, though likewise in a few studies (n= 3) it was unclear how the data was collected which indicated the remediation was performed. Only one study (n= 1) reported that the researchers measured radon remediation behaviour by remediations completed by a certified radon mitigator (e.g., contractor) (Bain, Abbott, & Miller, 2016). Both outcomes were reported either in terms of size and/or percentage of the population who demonstrated or reported the behaviour.

Were Socio-Demographic Characteristics Measured?

Socio-demographic characteristics of the participating population are important to measure in order to determine if a confounding variable moderates the reported relationship between the independent and dependent variables. Sociodemographic factors were measured in half the studies (n = 17). There was inconsistency in how sociodemographic factors such as age, education and socio-economic status were measured, and which scales were used.

III.IV Concluding Discussion of Methods Applied and Limitations

In conclusion, there are a few limitations or possible biases that should be highlighted. Many records used self-reported outcomes to measure behaviour related to indoor radon testing and/or remediation. Self-reported outcomes may be subject to response biases, such as social-desirability bias, and can be influenced with the communication and understanding of the intervention (Rosenman, Tennekoon, & Hill, 2011).

The variety of different research methods increases the difficulty of making any comparisons between research outcomes. As result, this heterogeneity impacts the ability to analyse possible relationship between the intervention characteristics and the indoor radon related behaviour. This is further exacerbated by the variety of ways socio-demographic characteristics are measured. Sociodemographic characteristics have been found to be related to determinants of radon risk behaviour (Hill et al., 2006), and therefore are important to take into consideration in the analysis of a systematic review. As such, it would be useful for future research to have guidance and standards on applied methodology to enhance our understanding of relationship between indoor radon testing and remediation behaviour and the characteristics associated with a communication intervention.

IV. Methods in investigating marketing approaches in NORM for building materials

IV.I Introduction

Industrial waste and by-products from certain industries such as coal, steel and phosphate are in many cases deposited into landfills. Depending on their radioactivity level, these residues can be categorized as naturally occurring radioactive materials (NORM). The potential of using these residues as a partial or total replacement of raw materials in the construction industry has been extensively studied (Schroeyers, 2017). Substituting natural resources used in building materials with residues can promote a circular economy and contribute to CO_2 emissions reduction (McLellan, Williams, Lay, van Riessen, & Corder, 2011). However, there are many factors that need to be evaluated in marketing these construction materials. Particularly the enhanced radioactivity level of these materials might pose societal challenges. This complex relation between sustainability benefits and radiological risk requires comprehensive understanding of stakeholders' opinions, attitudes and behaviours towards using NORM contained residues in building materials. This innovative topic will be studied in RadoNorm subtask 6.4.2, and requires a mix of methodological approaches.

IV.II Methodological approach

The first step in the research process was searching existing literature to identify studies in the social science domain with a focus on NORM in building materials. Web of Science and Scopus databases have been used to identify the relevant studies within this topic. The following keywords were used: radioact* OR ionising OR radiati* OR radionuclide OR "radioactive material" OR "Natural radioactivity" OR "Naturally occurring radioactive materials" OR "natural occurring radionuclides")) *AND* (("building material*" OR "building product*" OR "building industry" OR "construction material*" OR "construction product*" OR "construction industry")) *AND* ((social OR societ* OR marketing* OR public OR risk* OR attitude* OR perception* OR behaviour* OR stakeholder* OR commercial OR socio-economic OR nontechnical OR market* OR competition* OR acceptance OR "social acceptance" OR cost* OR economic OR user*)). In the Web of Science and Scopus database, 905 and 1,593 articles were found respectively. However, after assessing all publications found, none turned out to be relevant in terms of addressing the societal aspects and challenges of NORM in construction materials. The lack of publications in this area indicates the novelty of this PhD topic.

IV.III Reflections and further steps

As a guidance and inspiration for the methodology, literature that represents similar struggles and potential tensions between sustainability and risk aspects will therefore be explored. One of the most relevant fields in this regard is the social scientific work on CO_2 capture and utilization (CCU). The capturing of CO_2 with the purpose of recycling and reusing it facilitates the decarbonisation of the manufacturing process and contributes to the reduction of CO_2 emissions. On the other hand, the public might have concerns regarding the associated health risks of carbon-derived products.

Within this literature, van Heek et al.'s (2017) study investigates the acceptance of products which are based on CO_2 capture and utilization (CCU), by using a mattress as an example. This study first interviews experts and lay people to identify crucial acceptance factors. Then a conjoint analysis combined with a questionnaire is applied to examine the influence of product characteristics, and potential ecological and health risks on the acceptance of CCU products. Analysis of these relationships and interrelations provides a comprehensive understanding of factors affecting the acceptance of CCU.

Another relevant example in this field is a study by Broecks et al.'s (2016) on persuasiveness, importance and novelty of arguments about Carbon Capture and Storage (CCS). A discrete choice experiment is used in this study. This is an attribute-based survey method that presents participants

with different scenarios to choose from. This allows them to compare the complete product descriptions (multiple factors, such as e.g. price, sustainability, quality) rather than single elements in isolation; similar to real-world choice situations (M. G. Ryan, K. Amaya-Amaya, M., 2007). In previous CCS studies, this method has been used to identify the importance of different characteristics of CCS (see Wallquist, Seigo, Visschers, & Siegrist, 2012). However, in Broecks et al.'s (2016) study it has been used to examine participants' perceptions towards different arguments for or against CCU. In an online national survey, participants were distributed in two groups. Half of them responded to eight consecutive pairs of pro arguments and the other half to con arguments. This assisted in establishing the public's perception of proponents' and opponents' arguments about CCS, which can inform future communication.

The above methodologies can serve as an inspiration to social scientific studies on NORM in building materials. This exploratory study will have a mix of methodological approaches. First, qualitative methods such as interviews or focus groups can be used to explore stakeholders' perceptions and attitudes towards NORM containing building materials. Findings will assist in developing questionnaires or more innovative approaches such as choice experiments or conjoint analysis combined with a questionnaire. This will examine the complex relationship of different identified variables with acceptance of NORM contained materials. Furthermore, similar methods can be used to evaluate different marketing communication approaches.

V. Methods used in research on societal context of radon as treatment

V.I Introduction

Radon has been identified as the second leading cause of lung cancer, after smoking, and lies at the basis of 3 to 14% of lung cancer diagnoses (World Health Organization, 2009). (Inter)national authorities have hence presented and framed radon primarily in terms of health risks, raising people's awareness on the issue, and urging them to test their buildings for radon and, if necessary, take mitigating actions. At the same time, however, radon therapies and treatments are offered in spas across Europe, claiming positive health impacts of exposure to radon gas. As such, a controversy can arise from the opposing framing of 'radon as threat' versus 'radon as treatment. This apparent contradictory framing can have important consequences in terms of public confusion, complexities in designing and implementing communication campaigns, economic interests of particular stakeholders, etc.

In the RadoNorm project, particular attention is hence directed at this apparent controversy of 'radon as threat' vs 'radon as treatment'. Through studying the different framings, and the practices, stakes and stakeholders involved, RadoNorm subtask 6.4.3 will gain understanding of this controversy, and will make recommendations on how it can be handled. More specifically, through analysing the framing of radon communication in the context of radon spas, and studying stakeholders' perceptions of and interests in these spas, this study gains insight in the issues at play in the controversy of 'radon as threat' versus 'radon as therapy', in order to reflect on how this controversy can best be handled in the context of radon communication.

Although the aim of RadoNorm subtask 6.4.3 is in no way directed at assessing the effectiveness of radon therapies, the effects of exposure, or the medical conditions of radon spa visitors, studying a controversy implicates a heightened attention for the methods used in gathering, analysing and reporting data. Particular attention should be directed at how this data can be obtained and used in an ethical and responsible way. An important research step therefore consisted in identifying previous social scientific studies on radon spas, with a particular focus on the methods used.

V.II Literature search

A literature search was conducted with the help of the Web of Science™ and Scopus® databases, in order to obtain a wide journal coverage (Mongeon & Paul-Hus, 2016). The search words used were "radon spa" OR "radon bath" OR "radon therapy". After importing the found records to Endnote 20 and removing duplicates, a database was obtained of 386 records. Each record was subsequently scanned, in order to identify social scientific work related to radon spas and/or therapies.

Only four records were retained, as the large majority of the database consisted of publications either focused on medical issues, or on radon measurements and assessments. Of these four records, one was a historical study of radon therapies in the 1930s, with a focus on Canada, and hence was also excluded. The three remaining records were all authored by Barbra Erickson (B. E. Erickson, 2004; B. E. Erickson, 2007a, 2007c). The 2004 publication concerned a conference contribution. A google search demonstrated that this conference contribution was published later (potentially in an adapted form) in Dose-Response (B. E. Erickson, 2007b). It are these three articles, all published in 2007, which formed the (limited) corpus through which we explored previous social scientific work and methods on radon spas and therapies.

V.III Main results

The main body of data on which Erickson built her three articles, were gathered through loosely-structured, open-ended interviews with clients of a radon health mine in southwestern Montana. These interviews primarily focused on respondents' choice and explanation for using radon therapies in the treatment of their illnesses. Interviews were conducted on site, in a period ranging from 1997 until 2002. Additionally, the author used information obtained through information cards kept by the mine owners on visitors' age, occupation, state of residence and self-reported medical condition. The articles provide also some insight in the activities taking place in the studied health mine, although there is no reporting on any form of systematic observation. In one study, also the use of a questionnaire distributed to clients through the mine owners is mentioned (B. E. Erickson, 2007c). This questionnaire consisted of questions related to demographics and health, and "written comments" (B. E. Erickson, 2007c, p. 3). In another study, data is mentioned which was gathered during 'trips to Europe' in which the author "visited three spas, one radon steam bath, two curative tunnels, and one radon mine", and interviewed medical staff (B. E. Erickson, 2007b, p. 55).

While limited in number, the three studies by Erickson do provide some inspiration for data gathering regarding the apparent controversy between 'radon as threat' and 'radon as treatment', especially regarding on-site interviews with clients and staff. However, little information is provided on the actual conduct of these interviews, and how they were analysed/used for the purpose of the study. Moreover, other stakeholders related to the controversy (e.g. health authorities, marketing staff, local population) have not been included in the study, nor has systematic attention been directed to the actual practices taking place in/around the radon mines or spas. Additional methodological inspiration can therefore be found in studies on health controversies in other, but partially related, fields. Studies on (medical) marijuana or alcohol use have for example employed content analysis to understand how news, entertainment, or other communication channels have framed these topics (e.g. Lynch, 2020; Van Den Bulck, Simons, & Gorp, 2008). Also ethnographic methods have been used to get a better comprehension of how practices were enacted, building not only on interviews, but also systematic observations (e.g. H. W. Feldman & Mandel, 1998). As such, these fields can also provide input for methods to be used in understanding radon spa controversies.

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