



## **Deliverable 6.11**

### **Citizen Science for improved and sustainable protection for radon exposure situations**

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 establish a citizen science incubator for radon priority areas and a network of citizen science projects to address radon testing and mitigation. For this, one of the first tasks within RadoNorm was to develop and test four citizen science pilot projects in France, Hungary, Ireland and Norway in order to propose a model for citizen science in EU Member State. Through an open call, six citizen science projects were funded: **OCRA in Italy, AHS Radon Hunt in Poland, RadAR in Portugal, RadonGPS in Slovakia, RadoNorm-SLO in Slovenia and RADOHOW in Spain**. In addition, **RadoNorm Aerosol** in Hungary continued its activities beyond the pilot phase of RadoNorm and was also part of the Citizen Science Incubator. Deliverable 6.10 presents the final reports of all citizen science projects. This deliverable 6.11 contains the four publications resulting from Task 6.3 and which include our recommendations for empowering citizen science initiatives related to radon exposure. These are the following:

- Martell, M., Perko, T., Tomkiv, Y., Long, S., Dowdall, A., Kenens, J. (2021) Evaluation of citizen science contributions to radon research. Journal of Environmental Radioactivity 237. <https://doi.org/10.1016/j.jenvrad.2021.106685>
- Filograna, A., Martell, M. and Gignac (2023) Citizen engagement, motivation and recruitment, Citizen science lighthouse, December 2023. The digital magazine of the European Citizen Science collaboration group.
- Hoedoafia MA, Martell M and Perko T (2024) Evaluating citizen science projects: insights from radon research. Front. Environ. Sci. 12:1436283. doi: 10.3389/fenvs.2024.1436283
- Martell, M., Perko T. and Hoedoafia MA (2025) Evaluation of the RadoNorm Citizen Science Incubator (in submission).
- Chapter “radon and citizen science” co-authored by the WP6 leader (Tanja Perko) and the Task leader on citizen science (Meritxell Martell) and all the coordinators of the pilot citizen science projects (Sylvain Andresz and Caroline Schieber in France, Yevgeniya Tomkiv in Norway, Alison Dowdall and Leo McKittrick in Ireland and Veronika Oláhné Groma in Hungary) published in the book “Communicating Public Health Risk. The Case of Radon Gas” edited by José Sixto-García, Sara Pérez-Seijo and Berta García-Orosa (2025).
- Perko, T. Martell, M., Hoedoafia MA (2025) Beyond Data Collection: Unravelling the Motivations Driving Citizen Scientist Engagement (submitted in Nature - Humanities and Social Sciences Communications).

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## Acronyms

CEPN – Nuclear Protection Evaluation Centre (France)

CS – Citizen Science

CSMS – Citizen Science Motivation Scale

CSP – Citizen Science Projects

DIY – Do It Yourself

EC – European Commission

ECSA - European Citizen Science Association

EPA – Environmental Protection Agency (Ireland)

HEIA - High School of Engineering and Architecture Freiburg (Switzerland)

IAEA – International Atomic Energy Agency

ICRP – International Commission for Radiological Protection

INFN - Istituto Nazionale di Fisica Nucleare (Ital)

KMO – Kaiser-Mayer-Olkin

NMBU /CERAD – Norwegian University of Life Sciences / Centre for Environmental Radioactivity

NSD - Norwegian centre for research data

SDT – Self-Determination Theory

WHO – World Health Organisation

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## 1. Evaluation of citizen science contributions to radon research

In order to reduce lung cancer due to radon exposure situations, not only authorities and organisations but also citizens may meaningfully contribute to radon mitigation actions. Citizen science (CS) initiatives are recognised for their scientific, societal and policy value related to environmental issues. The purpose of this paper is to identify which CS initiatives in the field of radon exist and evaluate to what extent these CS initiatives contribute to radon research and/or radiation protection from radon. We conducted a systematic review of internet pages and scientific literature (September-December 2020) as well as expert consultation to help us identify and assess CS initiatives on radon (September 2020-February 2021). The ten principles of the European Citizen Science Association have been used as a starting point to develop indicators for the analysis of CS contributions to radon research. The results show that there are at least eight CS initiatives in the world contributing to radon related research which comply, to some degree, with each of the ten principles. In all these initiatives citizens contributed or are contributing meaningfully to radon testing and measurements. However, most of them apply the simplest form of participation (crowdsourcing) and only one focuses on radon mitigation. Moreover, unlike CS initiatives in other environmental areas, those focusing on radon are always led by the authorities and/or universities, in a top-down manner. Yet, results confirm that both the experts in radon-related fields and the citizen scientists from radon prone areas benefit from taking part in radon CS initiatives. Experiences and lessons learned in radon related to CS initiatives are identified and discussed in order to inspire future CS initiatives potentially contributing to reducing exposure to radon as well as to the implementation of national radon action plans.

Keywords: Citizen science, radon, mitigation, citizen engagement, participatory research, crowdsourcing

### 1.1 Introduction

Citizen science (CS) initiatives, the process whereby citizens are involved in science as researchers (Conrad & Hilchey, 2011; Oberle et al., 2019), have the potential to contribute to the implementation of radon action plans required by international organisations (IAEA, 2015; WHO, 2009; Euratom, 2013). CS can provide means for continuous monitoring (Keller et al., 2019; Turcanu et al., 2020), improve radon awareness and address the 'value-action gap' where the values or attitudes of an individual (e.g. health as a value) do not correlate to his or her actions (e.g. test for radon and fix the house) (Perko & Turcanu, 2019).

The research questions addressed in this study are:

*"Which CS initiatives in the field of radon exist and how to evaluate them?"*

*"To what extent these CS initiatives in the field of radon contribute to radon research and / or radiation protection from radon?"*

A novel evaluation metric was developed and applied for the analysis of CS contributions based on the ten principles of the European Citizen Science Association (ECSA), which can be used as a tool for future CS projects in a field of radon.

This study utilises a combination of methods: a scoping review of CS related databases (Peters et al., 2015), a systematic review of literature, the snowball method, an expert consultation workshop<sup>1</sup>, and interviews for clarification and validation of results. This study was conducted in the framework of the Horizon 2020 RadoNorm project<sup>2</sup> whose aim is to manage risk from radon and NORM exposure situations to assure effective radiation protection based on improved scientific evidence and social considerations. Based on the review of CS initiatives, RadoNorm intends to design and test a CS model for radon mitigation actions.

### 1.1.1 Citizen science initiatives related to ionising radiation

CS is a flexible concept that can be adapted to different situations and disciplines (ECSA, 2020; Robinson et al., 2018). It is increasingly viewed as an umbrella term for the different ways in which citizens are involved in scientific activities (ECSA, 2020; Hecker et al., 2018; Irwin, 1995). CS has been widely recognised for its scientific, societal and policy value. Although CS projects have been conducted in the field of radiation protection and in the aftermath of nuclear accidents (Gricar & Baratta, 1983; Angelique & Culley, 2014a, b; Walsh, 1981; Brown et al., 2016; Kenens, 2020), information is still lacking regarding its current and potential contribution to radon research. In the case of radon, an invisible gas with long term health effects, CS initiatives can prompt behavioural change such as test or mitigate (EC, 2020). Citizen scientists can be extremely valuable in facilitating access to data for researchers, as they can monitor their health and their surrounding environment (Cooper, 2016). Monitoring is considered an important tool in CS. However, Conrad and Hilchey (2011) point out that in line with the recent developments in the field of CS, community-based monitoring should also include community-based management. CS can also become a means to help understand a scientific issue as well as to raise awareness about environmental governance (Blaney et al., 2016).

Different typologies are available for evaluation of CS initiatives (Wiggins and Crowston, 2011; Shirk et al. 2012; Bonney et al., 2009). For this paper, we adopt Haklay's (2013) typology of participation across the range of CS activities which goes from level 1 "*crowdsourcing*" to level 4 "*extreme citizen science*" and apply it to radon research, as shown in Table 1.1. For each level, references of CS initiatives in the field of ionising radiation are provided.

<sup>1</sup> Expert consultation on investigating the potential of citizen science for effective radon measurement and mitigation as part of the RICOMET conference held on 2 September 2020, on-line accessible at: <https://www.youtube.com/watch?v=WpVzO6LuKT8&t=243s> (last accessed May 2021).

<sup>2</sup> See <https://www.radonorm.eu> (last accessed May 2021).

Table 1.1 Levels of participation and engagement in CS initiatives applied to radon research

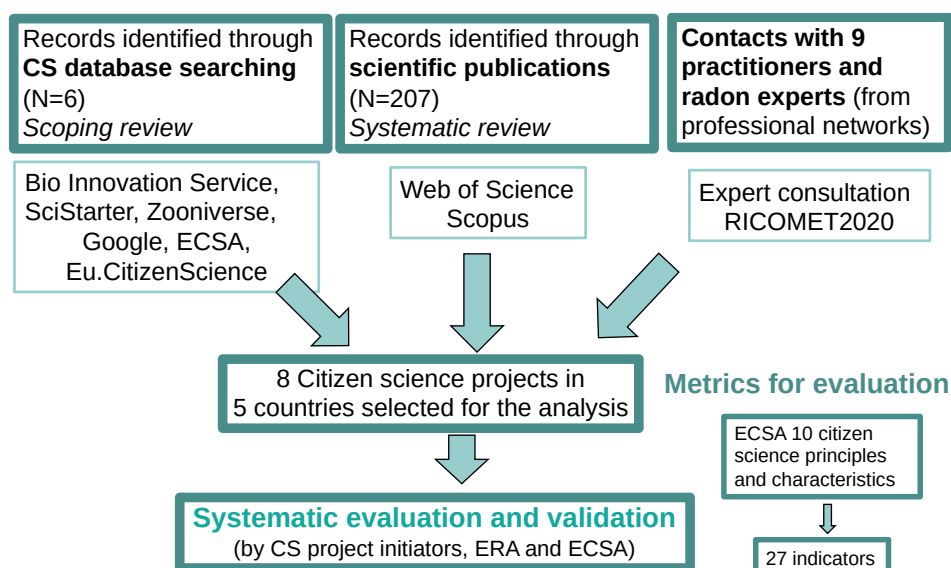
| Levels according to Haklay (2013) |                          | Radon research objectives                                                                                                                                                                                                                                                                                     | Examples in the field of ionising radiation                                                                                                  |
|-----------------------------------|--------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| Level 1.                          | Crowdsourcing            | A centralised organisation recruits citizen who contribute to research by conducting radon measurements and collecting basic data (e.g. house type, year of construction, etc) according to a predefined protocol. The data are sent back to a centralised organisation for interpretation and dissemination. | D-Shuttle project in Japan (Naito & Uesaka, 2018)<br><br>Project Ramesis in Czech Republic (Helebrant & Kuča, 2019)                          |
| Level 2.                          | Distributed intelligence | Projects are designed by scientists, and members of the public contribute with data, but also help with basic interpretation of the radon data.                                                                                                                                                               | OpenRadiation in France (Bottolier-Depois et al. 2017)                                                                                       |
| Level 3.                          | Participatory science    | Citizens refine the research questions, contribute to data collection, adjust protocols, draw conclusions and draft reports.                                                                                                                                                                                  | CS at the Mexican Mesoamerican Reef (Fulton et al. 2018)                                                                                     |
| Level 4.                          | Extreme citizen science  | Citizens are deeply engaged in most parts or the entire development of the scientific process together with researchers: defining the research question, collecting and analysing data, interpreting the data and disseminating the results (e.g. writing papers).                                            | The global radiation monitoring network Safecast (Brown et al. 2016)<br><br>Measurement project by high school students (Adachi et al. 2015) |

Level 1 is the simplest form of participation in which citizens act as sensors, have no influence on the project design and limited understanding about the whole project or the science behind it. In this case, participants may contribute to the scientific project in a passive way. The second level, called “*distributed intelligence*”, considers that citizens are basic interpreters and their cognitive ability is a resource that should be used. Citizens take some basic training, collect data or carry out basic interpretation activities. In level 3, “*participatory science*”, citizens participate in the problem definition and are engaged in data collection, but require the assistance of the experts in analysing and interpreting the results. Finally, level 4, “*extreme citizen science*” emphasises citizen involvement in many core activities of the scientific process, such as problem definition, data collection, analysis and interpretation (Haklay, 2013). Citizens here are considered co-creators of knowledge and solutions for societal challenges. Scientists here act as facilitators in addition to their role as experts. Whilst level 4 requires extensive involvement and engagement from citizens, level 1 asks for less input. Sometimes the opportunities to become more engaged in a research project evolve because participants request them (Land-Zandstra et al., 2021).

## 1.2 Method

This section describes the collection of data, indicators used for the analysis of CS initiatives and validation of results, as shown in Figure 1.1.

Figure 1.1 Methods used to collect and evaluate CS on radon



### 1.2.1 Collection and analysis of data

First, a scoping review of the following **CS related databases** using “radon” as a keyword was applied to identify CS records relevant to radon: i) inventory of CS projects for environmental policies undertaken as part of a study commissioned by the European Commission (Bio Innovation Service 2018)<sup>3</sup>; (ii) Queried SciStarter, an online database of CS projects from around the world<sup>4</sup>; (iii) Zooniverse, an online platform that hosts over 100 virtual CS projects from around the world<sup>5</sup>; (iv) Google internet search engine, using “radon” as a keyword and combinations of ‘citizen science’, ‘community-based monitoring’, ‘crowdsourcing’, ‘grassroot’; (v) the ECSA projects<sup>6</sup> and (vi) the EU.CitizenScience platform<sup>7</sup>.

Second, a systematic review of **scientific publications** was conducted. Articles for the review were collected in October 2020 using two search engines: Web of Science and Scopus. The years in which the resulting hits are published range from 1984 to 2020.

<sup>3</sup> Further information at: <https://data.jrc.ec.europa.eu/dataset/jrc-citsci-10004>

<sup>4</sup> <https://scistarter.org/>

<sup>5</sup> <https://www.zooniverse.org/>

<sup>6</sup> <https://ecsa.citizen-science.net>

<sup>7</sup> <https://eu-citizen.science/>

Our evaluation focuses on radon and therefore, articles on CS in the broader field of ionising radiation monitoring or radiation research were intentionally left out, e.g. Clewer et al., 2019; Gustavsson et al., 2020; Andersson-Sudén et al., 2019). Other initiatives were identified from the literature review, but were not considered for this paper, either because they could be primarily considered as radon surveys without meaningful citizen engagement (Dimitrova et al., 2011, Tushe et al., 2016, Rahlenbeck et al., 1992 or the EPA State Indoor Radon Grant Programme<sup>8</sup> to name a few) or because they were not a CS initiative on radon per se (Dowdall, 2017). On the latter, for instance, Keller et al. (2019) focused on the development of a mobile application to be potentially used for CS projects or in educational settings but it has not yet been applied. In addition, other projects might not have been included because they did not stand out by any of the search methods applied or are disseminated in a different language than English.

Third, **contacts with 9 radon experts and practitioners** were established based on professional networks and using the **snowball technique** to include ongoing and planned initiatives. For this, an on-line **expert consultation**<sup>9</sup> aimed at sharing experience on the existing and emerging CS initiatives on radon measurements was conducted in September 2020 as part of the RICOMET annual conference on social sciences and humanities in ionising radiation research<sup>9</sup>. The objective was to gather experts and professionals on CS and/or radon, share experience on the existing and emerging CS initiatives on radon measurements and explore the potential for CS to support effective radon measurement and most importantly, mitigation actions.<sup>10</sup>

### 1.2.2 Selection of CS initiatives for this analysis

**Characteristics (ECSA, 2020) and principles of CS (ECSA, 2015)** were used to develop indicators and systematically evaluate past and current CS initiatives in order to contribute to the national radon research. The identification of a CS project on radon was based primarily on two of the characteristics highlighted by the ECSA (2020). Firstly, the promoters or owners of the project had to have the intention to conduct a CS project and should have framed the project as such. Therefore, community-based research engaging certain groups on radon measurements, which can empower participants in other aspects of their lives and which follow some of the ten principles of CS, have been included in this evaluation. Traditional activities like national or regional surveys on radon concentration in dwellings, schools or workplaces, which are not conceived as CS activities, are not within the scope of this paper. Secondly, we include CS projects on radon which have a clear research goal and go beyond science outreach, educational activities or public awareness campaigns. In addition to these two criteria, CS projects had to be finished or currently on-going (at the time of the data collection) and information should have been available in English.

Whilst the classification of participation in CS activities according to Haklay (2013) allows us to understand the complex nature of participation, our aim here is to provide a detailed analysis of how CS initiatives can contribute to radon research. Therefore, we used the ten principles of CS provided by ECSA (2015) as a starting point, to illuminate how scientists and citizens can interact with each other in the research process and, to what extent CS can contribute to radon measurements and mitigation. To ease the analysis of CS initiatives, each principle was converted into a set of one or more questions (or

<sup>8</sup> <https://www.epa.gov/radon/state-indoor-radon-grant-sirg-program> (last accessed May 2021).

<sup>9</sup> See RICOMET website for 2020: <https://bit.ly/32CakoG> and the RICOMET2020 webinars at: <https://www.ssh-share.eu/ricomet2021/ricomet2020webinars/> (last accessed May 2021).

<sup>10</sup> Speakers presented the following organisations or projects: ECSA; Curious Noses project from the University of Antwerp, Belgium; Environmental Protection Agency (EPA) of Ireland; Technion University Israel Institute of Technology, Israel; University of Calgary, Canada and the European Radon Association (ERA).

indicators) related specifically to radon research. For each of the principle's formulation and explanation, we started with the definition provided by ECSA. Additional questions were included when we felt the ECSA definition could be supplemented by another perspective which brought an added value to the principle and served us to answer whether the principle was fully met or not. The formulation of the questions or indicators is shown in Table 1.2.

The CS initiatives identified in this study were analysed based on the questions in Table 1.2. Scientific references and internet websites were scrutinized to answer as many questions as possible.

### 1.2.3 Validation of results

Individual **interviews** were conducted with the experts who launched and are implementing CS projects, in order to perform respondent validation (Guba et al., 1994) of the indicators and the results of the preliminary evaluation provided by the RadoNorm team. Additionally, the draft of this study was sent to the panellists of the expert consultation, CS projects' initiators, European Radon Association (ERA) and ECSA for validation.

Table 1.2 Indicators to evaluate the contribution of CS to radon research

| <b>ECSA principle</b>                                                                                                                         | <b>Indicator / question</b>                                                                                                         |
|-----------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|
| 1. Citizen science projects actively involve citizens in scientific endeavour that generates new knowledge or understanding                   | Do citizens act as radon sensors or measuring points to collect radon data?                                                         |
|                                                                                                                                               | Are citizens actively involved in the project?                                                                                      |
|                                                                                                                                               | Does the project generate new knowledge or understanding regarding radon?                                                           |
| 2. Citizen science projects have a genuine science outcome                                                                                    | Is there a specific research question answered in addition to identification of homes with high levels of radon?                    |
|                                                                                                                                               | Does the project inform a policy or a decision on radon management?                                                                 |
| 3. Both the professional scientists and the citizen scientists benefit from taking part                                                       | Do both professional scientists and citizens benefit from participating in the project?<br>If yes, what benefits can be identified? |
| 4. Citizen scientists may, if they wish, participate in multiple stages of the scientific process.                                            | Do citizen scientists participate in the problem definition?                                                                        |
|                                                                                                                                               | Do citizen scientists participate in developing the research question?                                                              |
|                                                                                                                                               | Do citizen scientists participate in the design of the research method?                                                             |
|                                                                                                                                               | Do citizen scientists gather data?                                                                                                  |
|                                                                                                                                               | Do citizen scientists analyse or interpret data?                                                                                    |
|                                                                                                                                               | Do citizen scientists communicate or disseminate results?                                                                           |
| 5. Citizen scientists receive feedback from the project                                                                                       | Are citizen scientists informed of how their data are being used?                                                                   |
|                                                                                                                                               | Are citizen scientists informed of the research outcomes?                                                                           |
|                                                                                                                                               | Are citizen scientists informed of the policy or societal outcomes?                                                                 |
| 6. Citizen science is considered a research approach like any other, with limitations and biases that should be considered and controlled for | Do professional scientists identify the limitations and biases associated with the CS approach?                                     |

| ECSA principle                                                                                                                                                                                                                                    | Indicator / question                                                                                        |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                                                                                                   |                                                                                                             |
| 7. Citizen science project data and meta-data are made publicly available and where possible, results are published in an open access format                                                                                                      | Is CS project data publicly available?                                                                      |
|                                                                                                                                                                                                                                                   | Are results published in an open access format?                                                             |
| 8. Citizen scientists are acknowledged in project results and publications.                                                                                                                                                                       | Are citizen scientists acknowledged in the research publications?                                           |
|                                                                                                                                                                                                                                                   | Are citizens co-authored in the research publications? <sup>11</sup>                                        |
| 9. Citizen science programmes are evaluated for their scientific output, data quality, participant experience and wider societal or policy impact.                                                                                                | Is the scientific output of the CS programme evaluated?                                                     |
|                                                                                                                                                                                                                                                   | Is the quality of the data evaluated?                                                                       |
|                                                                                                                                                                                                                                                   | Is the participant experience evaluated?                                                                    |
|                                                                                                                                                                                                                                                   | Is the societal or policy impact evaluated?                                                                 |
| 10. The leaders of citizen science projects take into consideration legal and ethical issues surrounding copyright, intellectual property, data sharing agreements, confidentiality, attribution, and the environmental impact of any activities. | Are there clear principles and guidelines regarding legal and ethical issues?                               |
|                                                                                                                                                                                                                                                   | Is there a code of research integrity to which all actors must adhere?                                      |
|                                                                                                                                                                                                                                                   | Is there a research ethics consent form available (e.g. anonymity, informed consent, data management, etc)? |

<sup>11</sup> See examples of Adachi et al. (2015) and Lintott et al. (2009) including citizen scientists as co-authors in scientific publications.

## 1.3 Results

### 1.3.1 Citizen science initiatives in the field of radon

We identified eight past or on-going CS initiatives related to radon Table 1.3 from five countries (Canada, Ireland, Israel, Italy and the United States). The Canadian CS project is organised by Evict Radon, a non-profit organisation dedicated to solving radon gas exposure problems in Canada. Evict Radon has several research strategies across disciplines that vary from understanding the impact of building practices on radon levels to policy changes needed in radon (Stanley et al., 2017; 2019; Oberle et al., 2019; Simms et al., 2021). They engage citizens primarily as sensors and this initiative is therefore classified as level 1 (crowdsourcing).

The Environmental Protection Agency (EPA Ireland) launched a CS project in collaboration with Wexford libraries in November 2019 (extended to another library from November 2020). Library members are offered the opportunity to borrow a digital radon monitor for one month. The target group is library members (householders) that had previously carried out a three-month radon test showing concentrations above the national reference level (200 Bq/m<sup>3</sup>) but not carried out remedial work to reduce their exposure. By visually confirming with the digital monitor that their radon levels remain above the action level, these householders are encouraged to carry out remediation. Where the digital monitor indicated high radon levels for those that had not previously carried out a three-month test, there is a recommendation to take a three-month test before taking a remediation action. This initiative engages citizens not only to collect data but also to interpret it. Citizens take some basic training and the type of engagement could be classified as level 2 (distributed intelligence).

The main goal of the radon project in Israel is to study the patterns of radon temporal variations in Israeli buildings for the standardization of radon testing methods and optimization of large-scale (mass) measurement strategy. An additional objective is to conduct mass measurements in dwellings to assess the radiation dose to the Israeli population due to radon, as well as to identify buildings with high concentrations of radon. Although the project started carrying out indoor radon measurements in the dwellings of the employees of the Department of Building Materials, Performance and Technology of Technion Israel Institute of Technology, it was then expanded to the dwellings of school children, thanks to the active participation of the Taking Citizen Science to Schools Centre. If the test results from the screening conducted by school children show high levels of radon, professionals take additional more accurate measurements. In the near future, it is foreseen that schools will also be able to build living labs and hence, involve a broader part of the population to take radon measurements. In this initiative, citizen scientists contribute in a passive way following the level 1 of participation (crowdsourcing).

A CS initiative undertaken in Italy under the name RADIOactivity-LABoratory involves secondary school students and has CS as its main objective. This project is supported by the Istituto Nazionale di Fisica Nucleare (INFN) from 2005, as a continuation of the previous ENVIRAD project, which provided good scientific results and increased student engagement (Esposito et al., 2005). Nine of the INFN section currently participate<sup>12</sup>. The RadioLab project aims to carry out effective action to spread scientific culture through the involvement of high school students in environmental radioactivity measurements, in particular, that of natural origin and radon. In addition to performing measurements, students also distribute face-to-face questionnaires among the population to assess the levels of risk perception and

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<sup>12</sup> <https://www.dsfta.unisi.it/en/research/labs/physics-education-research-laboratory/radiolab> (last accessed February 2021).

knowledge on radon, carrying out dissemination activities at the same time (D'Avino et al., 2020). The initiative may engage citizen scientists at the level 2 (distributed intelligence).

We have identified four initiatives in the United States (US)<sup>13</sup> which we have considered for analysis in this paper. The first two initiatives describe pilot projects set up in Worcester, Massachusetts and Navajo Nation, New Mexico, using community-based participatory research in marginalised communities. The former comprises four partners (a youth centre, an environmental non-profit, a community-based health centre and a university) in which residents and researchers tested fourteen homes for, among other aspects, radon in basement air, in Worcester (Downs et al., 2009, 2010). Monitoring of neighbourhood particulates by residents and researchers used real-time data to stimulate dialogue. In this project, citizens participate in the problem definition and are engaged in data collection, but require the assistance of the experts in analysing and interpreting the results. Thus, the level of engagement in this initiative can be considered as level 3 (participatory science). The latter refers to a home radon survey designed and completed in collaboration with the Navajo Nation in the framework of the Community Uranium Exposure Journey to Healing Programme in New Mexico (Yazzie et al. 2020). Short-term indoor radon kits were used to measure indoor radon levels in 51 homes for a minimum of 3 days and not more than 7 days. We identify this programme as level 1 of engagement (crowdsourcing).

Another US based CS project is organised by the Office of Sustainable Practices, the Tennessee Department of Environment and Conservation.<sup>14</sup> They offer a number of services and assistance such as test kits for homeowners, technical information for universities, and specific materials for targeted audiences such as real estate professionals, home builders, building codes officials, home inspectors and school officials. Through the CS programme, information is provided to the state to identify specific areas where radon may be more likely to occur. In this case, we can identify this project as level 1 of engagement (crowdsourcing).

Finally, a transdisciplinary community-academic project in Kentucky is running from February 2020 to November 2024 which addresses community concerns about lung cancer by identifying geological and atmospheric conditions that increase radon intrusion into homes, translating this knowledge into greater residential awareness of risk, enabling home radon testing and report back, and growing access to affordable and adequate radon mitigation. The project named RADAR (Residents Acting to Detect and Alleviate Radon) engages residents of rural Kentucky communities and trains them to rigorously collect data and interpret findings. The project involves citizen scientists and geologists to determine how new radon detection technology (i.e. Airthings) compares to traditional charcoal kits and outdoor soil radon measurements over a range of atmospheric and geological conditions to close a critical knowledge gap in the understanding of radon risk. The project also promotes library loan programmes to increase radon testing with 400 homeowners in four counties.<sup>15</sup> We identify this programme as level 2 of engagement (distributed intelligence).

<sup>13</sup> In 2021, the US EPA launched a CS project with students and community members to measure radon levels and provide a map of potential radon hot spots to support radon risk mitigation strategies in Puerto Rico. <https://www.epa.gov/newsreleases/epa-embarks-innovative-research-projects-reduce-radon-risk-puerto-rico> (last accessed May 2021).

<sup>14</sup> <https://www.tn.gov/environment/program-areas/opsp-policy-and-sustainable-practices/community-programs-and-services/radon/citizen-science0.html> (last accessed February 2021).

<sup>15</sup> <https://www.research.uky.edu/news/researchers-awarded-26-million-engage-citizen-scientists-reduce-radon-exposure-rural-areas>; [https://tools.niehs.nih.gov/portfolio/index.cfm/portfolio/grantDetail/grant\\_number/R01ES030380](https://tools.niehs.nih.gov/portfolio/index.cfm/portfolio/grantDetail/grant_number/R01ES030380) (last accessed February 2021)

Table 1.3 Past and current CS initiatives related to radon

| Country | Programme initiative                               | Leader/ promoter                                            | Main aim of the programme / initiative                                                                    | Type of detectors used and duration of measurements | Number of tests / Timing                                                                                                                                                 | Supporting scientific evidence (references) / information on internet*                                                                                                                | Level of participation** based on Haklay's (2013) |
|---------|----------------------------------------------------|-------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|-----------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------|
| Canada  | Evict Radon                                        | Evict Radon, non-profit organisation, University of Calgary | Establish contextual effectiveness of distinct radon testing methods for decision-making; raise awareness | Alpha track radon detectors<br>/ 90+ day            | 11,727 residential tests (2010-2018)<br>18,971 (2015-2020)<br>Ongoing                                                                                                    | Oberle et al. 2019<br>Stanley et al., 2017, 2019, 2021<br><a href="http://www.evictradon.org">www.evictradon.org</a>                                                                  | 1) Crowdsourcing                                  |
| Ireland | Pilot citizen science project in Wexford libraries | Environmental Protection Agency (EPA) Ireland               | Re-test and encourage remediation                                                                         | Airthings (Corentium Home) / 1 month                | 20 monitors available in each library. Borrowed approximately 120 times /<br><br>November 2019 - ongoing (first library)<br><br>November 2020 – ongoing (second library) | <a href="https://www.epa.ie/take-action/in-the-community/citizen-science/clean-air-projects/">https://www.epa.ie/take-action/in-the-community/citizen-science/clean-air-projects/</a> | 2) Distributed intelligence                       |

| Country       | Programme / initiative                                        | Leader/ promoter                                                                   | Main aim of the programme / initiative                            | Type of detectors used and duration of measurements                                                             | Number of tests / Timing                                                                                                                             | Supporting scientific evidence (references) / information on internet*                                                                                                    | Level of participation** based on Haklay's (2013) |
|---------------|---------------------------------------------------------------|------------------------------------------------------------------------------------|-------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------|
|               |                                                               |                                                                                    |                                                                   |                                                                                                                 |                                                                                                                                                      |                                                                                                                                                                           |                                                   |
| Israel        | Radon Project                                                 | Technion Israel Institute of Technology & Taking Citizen Science to Schools Centre | Educate students on radioactivity; raise awareness; radon mapping | Charcoal method consisting of BDB-13 detector and several samples with CF-13 charcoal flacon/ average of 4 days | 400 tests / Dec 2018 – May 2019<br><br>Ongoing                                                                                                       | <b>Tsapalov et al. 2020</b><br>Tsapalov et al., 2018<br><a href="https://nbri.net.technion.ac.il/en/radon-project/">https://nbri.net.technion.ac.il/en/radon-project/</a> | 1) Crowdsourcing                                  |
| Italy         | Radioactivity Laboratory                                      | Istituto Nazionale di Fisica Nucleare (INFN)                                       | Educate students on radioactivity and raise awareness             | Electret passive environmental radon monitors (E-perm®), 3 months                                               | 25 students involved of one school in 2017; in the other 2 schools activities on radon involves questionnaires and communication activities. Ongoing | <b>Pugliese et al., 2019</b><br>D'Avino et al., 2020                                                                                                                      | 2) Distributed intelligence                       |
| United States | Main South/Piedmont neighborhoods of Worcester, Massachusetts | Clark University, Worcester Youth Center, Regional Environmental                   | Pilot participatory research, testing and reporting in            | Pro-Lab Radon liquid gas detection canisters / 48+ hours.                                                       | 8 homes in phase I in summer 2006 and 6 others in winter 2007 in phase II                                                                            | <b>Downs et al. 2010</b><br>Downs et al. 2009                                                                                                                             | 3) Participatory science                          |

| Country | Programme / initiative                                              | Leader/ promoter                                                     | Main aim of the programme / initiative                                | Type of detectors used and duration of measurements                                                              | Number of tests / Timing                                                                                                                                                                                                                                             | Supporting scientific evidence (references) / information on internet*                                                                                      | Level of participation** based on Haklay's (2013) |
|---------|---------------------------------------------------------------------|----------------------------------------------------------------------|-----------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------|
|         |                                                                     | Council and Family Health Centre                                     | vulnerable groups                                                     |                                                                                                                  |                                                                                                                                                                                                                                                                      |                                                                                                                                                             |                                                   |
|         | Tennessee Radon Program                                             | Department of Environment and Conservation of the State of Tennessee | Radon mapping                                                         | Air Chek Test kit / Maximum 5 days                                                                               | n/a<br>Ongoing                                                                                                                                                                                                                                                       | <a href="https://www.tn.gov/environment/sustainability/programs/radon.html">https://www.tn.gov/environment/sustainability/programs/radon.html</a>           | 1)<br>Crowdsourcing                               |
|         | Radon on the RADAR (Residents Action to Detect and Alleviate Radon) | University of Kentucky                                               | Collect and interpret radon measurements;<br>Increase radon awareness | Airthings detection technology will be used and compared with charcoal kits and outdoor soil radon measurements. | The pilot radon detector library loan program will cover 400 homeowners in the four counties.<br><br>60 community residents will be trained to test for radon and evaluate change in environmental health literacy and self-efficacy (February 2020 - November 2024) | <a href="https://www.niehs.nih.gov/research/supported/translational/rta/cfg/uky">https://www.niehs.nih.gov/research/supported/translational/rta/cfg/uky</a> | 2) Distributed intelligence                       |
|         | Navajo Nation Radon Program                                         | Community Uranium Exposure Journey to Healing Programme              | Assess the impact of housing features and                             | Air Chek, Inc. Kit                                                                                               | 51 households / November 2014-May 2015                                                                                                                                                                                                                               | Yazzie et al. 2020                                                                                                                                          | 1)<br>Crowdsourcing                               |

| Country | Programme / initiative | Leader/ promoter | Main aim of the programme / initiative                                               | Type of detectors used and duration of measurements | Number of tests / Timing | Supporting scientific evidence (references) / information on internet* | Level of participation** based on Haklay's (2013) |
|---------|------------------------|------------------|--------------------------------------------------------------------------------------|-----------------------------------------------------|--------------------------|------------------------------------------------------------------------|---------------------------------------------------|
|         |                        |                  | environmental factors on home indoor radon concentration levels on the Navajo Nation | Minimum of 3 days and not more than 7 days          |                          |                                                                        |                                                   |

\* In black the article to which the radon detector and measurements refer.

\*\*1=crowdsourcing, 2=distributed intelligence, 3=participatory science, 4=extreme citizen science

### 1.3.2 Evaluation of CS initiatives contributing to radon research

The eight CS projects related to radon Table 1.3 have been evaluated taking the developed method (Figure 1 and method section).

#### 1.3.2.1 CS projects actively involve citizens in scientific endeavour

All eight CS initiatives involved citizens as radon sensors or measuring points to collect radon, but not beyond collection of data. In some initiatives, like in Israel, it is the school children who conduct short-term radon tests in their homes (Tsapalov et al., 2020). Citizens may also contribute to the scientific endeavour. In the Evict Radon Canada initiative, citizen scientists proactively contact the researchers to give them feedback on the questions posed in the measurement questionnaires.

#### 1.3.2.2 CS projects have a genuine scientific outcome

In the majority of the analysed cases, new knowledge or understanding regarding radon is generated. In most cases, the scientific outcome consists of the assessments of building characteristics versus radon concentrations and the estimation of geographic weighted national average concentrations. In Canada, the identification of an increase in average level radon for newer homes suggested that modern building practices (larger, higher and more energy efficient homes) are associated with increased indoor radon (Stanley et al., 2017). It has been also found that younger North Americans are exposed to more radon gas due to occupancy biases within the residential built environment (Simms et al., 2021). Furthermore, Evict Radon helped to form the essential rationale for legislative action, in the form of the first ever Radon Testing and Awareness Act (Bill 2019).

#### 1.3.2.3 Both the professional scientists and the citizen scientists benefit from taking part

In all the CS initiatives analysed, there was a recognition of the benefits for both parts. On the one hand, scientists identify trends or issues which are of scientific interest to them, like the association of radon levels with building practices or seasonal tendencies. On the other hand, the benefits for citizens include their increased knowledge and awareness of indoor radon, the personal radon reading, the quality control of the testing provided and the free advice from professionals involved in the project (e.g. researchers in Canada; local contractor in Ireland) which can enable participants to take action. Remediation carried out by citizens results in a social benefit. In the case of Israel, the social benefit is linked to the educational process. As Tsapalov et al. (2020) argues: the *“involvement of schoolchildren is an important educational process, which contributes to the wide and rapid dissemination of information about the risks from radon among the population and administrations of different levels”*.

In some cases, like in Canada, a real estate education course was developed to educate professionals about radon in homes.<sup>16</sup> In other cases, the enjoyment of citizen scientists working with researchers is cited as a benefit (Downs et al., 2010) as is the potential to create networks in the rural communities by training residents to test for radon, as is one of the objectives of the Radon on the RADAR project being conducted in Kentucky.<sup>17</sup>

<sup>16</sup> Information at: <https://aref.ab.ca/real-estate-research-and-radon-course-aimed-at-keeping-albertans-safe-wins-international-award/> (last accessed February 2021).

<sup>17</sup> <https://uknow.uky.edu/research/researchers-awarded-26-million-engage-citizen-scientists-reduce-radon-exposure-rural-areas> (last accessed February 2021).

#### 1.3.2.4 Citizen scientists may, if they wish, participate in multiple stages of the scientific process.

In general, citizen scientists involved in radon measurements participate only in gathering data, by measuring radon in their homes and often, answering questionnaires. However, in Worcester, Massachusetts, the academic researchers and the community-based groups worked in a partnership to conceive, design, initiate and run the project consisting of testing homes for different hazardous air pollutants, radon in basement air being one of them (Downs et al., 2010). This partnership also engaged with residents who participated in participatory testing and reporting implementation.

#### 1.3.2.5 Citizen scientists receive feedback from the project

In all cases, citizen scientists are informed, from the start, of how their data are being used: either for the research project, the development of policy, the development of the radon map, etc. The way citizen scientists are informed is through the website, by phone, through an invitation letter asking them to take part in the survey, a mobile phone app or/and at a launch event. In all cases, citizen scientists are asked if they agree to share their data. Citizen scientists are also informed of the research outcomes as they receive the results of the measurements and recommendations for further actions, if necessary. Downs et al. (2009) argue that communicating testing results was integral to the goal of empowering residents in Worcester, Massachusetts. In their community based participatory project, they tailored reports for each home using an attractive design and a clear and concise wording. Community-based partners were key to translate the results.

#### 1.3.2.6 CS is considered a research approach like any other, with limitations and biases that should be considered and controlled for.

Some of the limitations highlighted by the scientists involved in the radon CS initiatives reviewed here include the lack of control of where the measurements are done. In Israel, the highest levels of radon (4 tests with values greater than 500 Bq/m<sup>3</sup>) were removed from the validated data set. It was found out that these 4 cases were the initiative of the schoolchildren themselves or their parents which tested radon in hermetically unoccupied shelters and therefore did not meet the sampling guidelines (Tsapalov et al., 2020). In the case of the Navajo nation, a selection bias and a non-response bias was identified. Some of the barriers identified to participation from a representative group were lack of access to a mobile phone or the preference of using the Navajo language at the first phone call (Yazzie et al., 2020).

Burke & Murphy (2011) analyse the representativeness of volunteer-based samples in radon measurement and explore the effect of potential volunteer bias on radon mapping results. They conclude that volunteer radon measurements should not be used for radon mapping purposes because they are biased due to over-sampling of high radon areas. Similarly, Levy & Small (1992) point out that bias is evident in data collected from volunteers and “regional databases developed from voluntary data generally exhibit higher mean values than those obtained from random samples”.

#### 1.3.2.7 CS project data and meta-data are made publicly available and where possible, results are published in an open access format

In the majority of cases, CS project data is publicly available, and the results are also published in an open access format. In a few cases, results are not published (e.g. EPA Ireland results). Most of the published scientific articles indicate that additional data and additional files with detailed results are available.

#### 1.3.2.8 Citizen scientists are acknowledged in project results and publications.

In most cases, citizen scientists are acknowledged in project results and publications. In the case of Israel, the mediators from the Taking CS to Schools involved in the initiative are co-authors of the

published papers (Tsapalov et al., 2020). In Massachusetts, the evaluation of the process and outcomes was jointly written by the partners (the academic researchers and the community-based groups) (Downs et al., 2010).

#### 1.3.2.9 CS programmes are evaluated for their scientific output, data quality, participant experience and wider societal or policy impact.

The scientific output and the quality of the data resulting from the CS programme is often evaluated as part of the peer reviewed process of scientific articles or by the evaluation committee which provides the funding for the initiative. In addition, the societal and policy impact might be evaluated not only by the funding agencies but also by government officials and stakeholder groups who support these initiatives.

The participants' experience can be evaluated in different ways, e.g. by the school teachers in Israel. In Canada, the results of Evict Radon were presented in 2017 and 2019 to all participants and interested persons at specific events. A large amount of time was devoted to feedback and questions and answers. As the initiative has become wider and national, these presentations are not practical and podcasts are now developed. In Ireland, EPA asked citizens for their feedback about the project, how they felt by participating in the project, the strengths and what could be improved.<sup>18</sup>

#### 1.3.2.10 The leaders of CS projects take into consideration legal and ethical issues surrounding copyright, intellectual property, data sharing agreements, confidentiality, attribution, and the environmental impact of any activities.

In some CS initiatives, specific principles and guidelines on legal and ethical issues were followed. Institutional review, ethics boards or governmental authorities had to approve the work to be conducted. In the case of the Israel Radon Map, the Ministry of Education needed to give permission to involve children in the measurement survey, subject to the consent of their parents and the protection of personal data (Tsapalov et al., 2020). The study design, methodology and data sharing between groups was approved by the Conjoint Health Research Ethics Board of the Research Services of the University of Calgary in Canada. In all cases, the personal data of participants is anonymised and informed consent is requested. In the Radon Map in Israel, the location of the points of indoor radon measurement is shown by intention with great uncertainty in order to maintain anonymity of the test participants. In Evict Radon, the smallest geographic region used to describe radon is a city quadrant (for major cities), an entire town or a federal electoral district.

### 1.3.3 Evaluation of CS initiatives contributing to radiation protection from radon

A significant limitation in the benefits experienced by citizen scientists is that, while they may have a better understanding of radon and be aware of their own exposure, with the exception of the project in Ireland, no attention is paid to reducing the exposure of the citizen scientists to radon.

As pointed out by Hevey (2017), there are many steps that an individual must take before they have protected themselves from radon exposure (Table 1.4). The CS initiatives evaluated in this research, if

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<sup>18</sup> The initial intention was to arrange a face to face meeting in March 2020. Due to the Covid-19 pandemic, this was postponed and was finally changed to a phone call with a number of questions formulated with the advice of a psychologist. Permission was asked to contact the participants and arrange followed up calls.

they have been successful in communicating with the citizen scientists, have brought the participants to steps 12, 13 or perhaps even 14 or 15. But all fall short of the most important final steps of reducing the radon exposure of the participants.

Table 1.4 Steps required for action to occur to reduce exposure from radon (Hevey, 2017) addressed in CS initiatives

| Step | Information processing and decision-making steps                                                                                                          | Behavioural change concepts             | Steps addressed in CS initiatives                                                                                                                                                                                                                   |
|------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1    | I am exposed to the information.                                                                                                                          | Knowledge/awareness                     | Evict Canada;<br>Radon project Israel;<br>Radioactivity Laboratory Italy;<br>US Main South/Piedmont neighbourhoods of Worcester, Massachusetts;<br>US Tennessee Radon program;<br>US Radon on the RADAR Kentucky;<br>US Navajo Nation Radon Program |
| 2    | I attend to the information (notice it)                                                                                                                   |                                         |                                                                                                                                                                                                                                                     |
| 3    | I am interested in the information                                                                                                                        |                                         |                                                                                                                                                                                                                                                     |
| 4    | I understand the information                                                                                                                              |                                         |                                                                                                                                                                                                                                                     |
| 5    | I believe that there is a threat: the information must be perceived as being credible                                                                     | Risk perception                         |                                                                                                                                                                                                                                                     |
| 6    | The threat is comprehensible: I understand the threat                                                                                                     |                                         |                                                                                                                                                                                                                                                     |
| 7    | I perceive it as a possible risk: the threat may affect me (I may be susceptible) and it may have very negative health consequences for me (it is severe) |                                         |                                                                                                                                                                                                                                                     |
| 8    | I believe that the threat level can be assessed                                                                                                           |                                         |                                                                                                                                                                                                                                                     |
| 9    | I know how to get the threat level assessed                                                                                                               | Knowledge/awareness                     |                                                                                                                                                                                                                                                     |
| 10   | I want to get the threat level assessed.                                                                                                                  | Motivation to act                       |                                                                                                                                                                                                                                                     |
| 11   | I act to get the threat level assessed: <b>test</b>                                                                                                       | <b>Action: Testing</b>                  |                                                                                                                                                                                                                                                     |
| 12   | I understand the results                                                                                                                                  | Knowledge/awareness                     |                                                                                                                                                                                                                                                     |
| 13   | I perceive that I am at risk (I am susceptible to a severe negative outcome)                                                                              | Risk perception                         |                                                                                                                                                                                                                                                     |
| 14   | <i>I want to reduce this risk</i>                                                                                                                         | Motivation to act                       | EPA Ireland                                                                                                                                                                                                                                         |
| 15   | <i>I know how to reduce this risk</i>                                                                                                                     | Knowledge/awareness                     |                                                                                                                                                                                                                                                     |
| 16   | <i>I act to reduce the risk: <b>remediate</b></i>                                                                                                         | <b>Action: Reduce exposure to radon</b> |                                                                                                                                                                                                                                                     |
| 17   | <i>I act to confirm that the risk has been managed: <b>re-test</b></i>                                                                                    |                                         |                                                                                                                                                                                                                                                     |

Source: adapted from Hevey (2017)

## 1.4 Discussion and conclusions

Most of the identified initiatives apply level 1 participation – crowdsourcing (Haklay, 2013) where the separation between scientists and citizens is clearly maintained and citizens participate in data collection only and are not part of scientific knowledge production. There are a few examples where we could claim that citizens had a role beyond data collection and are involved in interpreting data and disseminating results (Downs et al, 2020; Pugliese et al., 2019, the EPA Ireland initiative).

Our analysis has shown that the ten ECSA principles (2015) are a good starting point to develop indicators for identifying CS initiatives and assessing the extent to which CS initiatives contribute to radon research. Although none of the projects analysed here meet all ten principles fully, CS projects have proven their potential to contribute to radon measurements and radon research. They allow for active participation of citizens in different stages of research, generated scientific outcome, provided benefits for all participants and society in general.

In the context of radon, it is public authorities and researchers who often promote CS initiatives, in a top-down manner, unlike CS initiatives in other fields. This does not necessarily hamper the potential of CS initiatives. As Rubio-Iglesias et al. (2020) conclude after their analysis of how Environmental Protection Agencies are building on CS data and methodologies, *“the potential of citizen science clearly outweighs the concerns”* related mainly to data quality, trust of official measurements and expectation management.

None of the CS initiatives in the field of radon are registered in CS databases, which makes it a challenge for radon knowledge capacity and exchange lessons learned. It is important to make CS initiatives visible to the research community in order to facilitate mutual learning for all parties involved. Poor public awareness about radon in some countries may be an important motivation for authorities to support CS.

The research shows that CS initiatives may meaningfully contribute to national radon action plans and implementation of legal requirements. The development of CS initiatives which considers not only testing but also radon mitigation, may contribute to a decrease in radon related lung cancer, as suggested both in the Canadian case (Stanley et al., 2017) and in the case of Ireland, where citizens actively reduce the levels of radon exposure in their houses.

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## 2. Citizen engagement, motivation and recruitment

Citizen scientists are undoubtedly the vital essence of any citizen science project. Therefore, keeping an eye on what interests and motivates the citizens, and what they expect from their involvement in the project, is crucial to ensure not only the success but also the sustained longevity of citizen science initiatives. Yet, maintaining consistent engagement and ensuring citizens remain highly motivated throughout can pose a challenge for many citizen science initiatives. On October 7th 2023, Antonio Filograna from DECIDO and Meritxell Martell from RadoNorm organised a session, discussing strategies on how to engage citizens and, most importantly, keep them involved and motivated. This sparked some really interesting discussions and gave us some takeaways to think about.

**There is no single set of most effective engagement tools and strategies, but those that are tailored to specific groups and leverage networks and communities prove to be powerful.**

Before strategizing on how to engage citizens in a project, it is important to understand the type of participants you want to involve, as well as to be aware of their needs, motivations, and potential barriers to participation. In that case, a stakeholder mapping is always a good first step. Tools and strategies will highly depend on the target groups you aim to engage, which can range from announcements on TV shows and national news to newspapers, radio podcasts, social media campaigns, flyers, email invitations, etc. One strategy often overlooked is the power of the snowballing effect or word of mouth, which stands as an effective engagement strategy according to several members of the ECS Collaboration Group. This can be achieved by tapping into established community networks such as civil society organisations or local associations, attending their events and fostering collaborations. In RadoNorm, local libraries, local health authorities, word of mouth and the social media of local authorities have been crucial to recruit citizen scientists. Some groups have representatives and gatekeepers and their support can be harnessed and beneficial in spreading the word about the project. In the DECIDO project, a strategy to engage citizens was the Social Hackathon. This is nothing technical but, following the example of a hackathon, it involves various participants such as citizen organisations, businesses, NGOs, and policy makers who gathered together to brainstorm, analyse data, and ultimately find potential solutions to a problem, using the motto “Learn, discuss and then decide”. It is also important to note that the selection of engagement tools and strategies will significantly depend on the inclusivity objectives and ambitions you wish to address in your citizen science activities.

**Yes, motivations for participation are very diverse - but overall, fun must be present!**

After learning about projects from the ECS Collaboration Group, it is evident how motivations can significantly vary from one citizen to another and from one cultural context to another, even within a single project. Sometimes it is the desire to be part of something; other times, it is for personal reasons, such as acquiring new skills, or to enact change and contribute to evidence-based policymaking. Also, some seek to be recognized as equal stakeholders in policy changes. But ultimately, fun is a critical element in establishing and maintaining motivation. Participation should be enjoyable, especially considering that citizen scientists contribute during their leisure time without financial compensation. In this context, the adoption of a “gaming paradigm” fosters a sense of excitement among citizens, making their involvement more appealing and accessible. It transforms an otherwise daunting process into an enjoyable experience, attracting a wider range of citizens to actively participate.

**Citizen scientist dropouts are entirely normal and should serve as a catalyst for researchers to self-reflect on the reasons why participants disengage.**

Some level of dropout is natural in all projects. Instead of viewing this negatively, it can serve as an indicator of areas where the project may be lacking. There are different reasons for citizens to drop out. For instance, dropout rates can rise when citizen scientists lack trust or confidence in the project's

activities and their potential impact. This can be attributed to the fact that citizens may not directly witness the results or outcomes of their contributions. This may indicate a lack of transparency in the project. To mitigate this, it is thus crucial to clearly communicate what the project aims to achieve in each of its steps, as well as its limitations, especially when unexpected changes occur. Ensuring that citizens are well-informed about what they are accomplishing is also very important.

**Engagement is an ongoing effort and therefore, delegating efforts and adopting an adaptive approach to engagement strategies are key.**

Engaging citizens extends beyond a single moment, such as the recruitment phase, and it requires researchers to sustain efforts to keep project activities relevant until the end. While juggling various roles, researchers need to be pragmatic and strategically plan their involvement with citizen scientists. Ensuring that a designated person is responsible for maintaining transparency and communication is important and this can be done by considering incorporating facilitation experts or dedicating an individual exclusively to engagement efforts. Above all, adopting an adaptive approach throughout the project in terms of engaging citizens, which continually aligns with evolving or changing motivations, is paramount. In fact, engagement might need to be tailored to the specific lives and life stages people are in. This can influence their preferred and possible ways of participating in the project.

### 3. Evaluating citizen science projects: insights from radon research

Citizen science projects have garnered attention for their potential to engage the public in scientific research and address societal challenges. However, assessing their impacts has often been overlooked or approached with overly simplistic methods. Aiming to fill this gap, this article draws on existing literature to propose an evaluation framework to critically examine how citizen science initiatives influence science, society and the participants themselves. This framework is tested on four citizen sciences projects in the field of radon research through content analysis of project reports and deductive analysis of 11 semi-structured interviews with citizen scientists and coordinators of the projects. The study demonstrates the feasibility of measuring the impacts of citizen science projects across scientific, participant, societal and researcher dimensions at the outcome level but also process evaluation at the process level. Our findings indicate that the proposed framework provides a comprehensive evaluation tool for citizen science projects, particularly in the field of radon research, and underscore the significant potential for improving participants' knowledge on radon and risk mitigation strategies, as well as positive shifts in behaviour towards testing and mitigation and influencing public health policies.

**KEYWORDS:** citizen science, radon risk management, impact evaluation, radiation protection, citizen engagement, indoor air pollutant, Assessment, learning gains

#### 3.1 Introduction

Evaluating citizen science projects is essential for ensuring their effectiveness, enhancing planned outcomes, improving data quality, supporting scientific, educational and policy goals, among others. Citizen science (CS) has been evaluated based on the achievement of different outcomes: “outcomes for research (e.g., scientific findings); outcomes for individual participants (e.g., acquiring new skills or knowledge); and/or outcomes for social–ecological systems (e.g., influencing policies, building community capacity for decision making)” (Shirk et al., 2012: 1). However, comprehensive standardized frameworks which systematically assess the impacts of CS are scarce, either there is a lack of a

common framework (Kieslinger et al., 2018) or they are too simplistic (Somerwill and Wehn, 2022) or overlook relevant advancements in the field (Wehn et al., 2021).

In the field of public health risk radon, the evaluation of particular radon CS initiatives has mainly focused only on participants gains such as risk awareness and knowledge (Hahn et al., 2020; Stanifer et al., 2022; Tsapalov et al., 2020). Other aspects, for instance scientific and societal impacts or sustainability, have been overlooked. In a recent study, Martell et al. (2021) revealed that CS projects in the field of radon are few, despite the World Health Organization (2009) indicating that this radioactive indoor air pollutant is a severe public health problem. Martell et al. (2021) evaluated eight citizen science projects identified through a systematic review (covering the period 1984–October 2020) utilizing the ten principles of the European Citizen Science Association (ECSA). These projects were evaluated on the scientific outcome of projects, benefits to scientists and participants, ethical and legal considerations, data accessibility, scientific output, and the level of citizens engagement. However, a comprehensive framework and practical guidance for assessing a variety of CS projects impacts is still lacking.

The research question guiding this study is: what criteria and indicators can help to better evaluate the impact of CS projects, particularly those focusing on radon research? The purpose of this article is twofold: first, to develop a comprehensive evaluation framework based on existing CS literature, and second, to utilize the RadoNorm CS projects in the field of radon to test and refine this framework. This will include improving indicators for evaluating the effectiveness of CS projects and contributing to public health from multiple perspectives. The framework proposed assesses the impact of CS in the field of radon on five dimensions, enabling evaluation of both outcome and process level: 1) scientific, 2) participants, 3) wider societal impact, 4) learning gains to researchers and 5) process evaluation.

## 3.2 Theoretical background: citizen science impact evaluation

The literature on CS impact evaluation reveals diverse approaches and frameworks employed to assess the effects of projects on different measures. Some studies have assessed CS impacts broadly on society, the economy, the environment, science, technology, and governance (Wehn et al., 2021; Bonney et al., 2014), whilst others have focused on the gains experienced by individual participants, such as learning outcomes, behavioural changes, scientific skills and personal empowerment (Stanifer et al., 2022; Trumbull et al., 2000; Phillips et al., 2018; Den Broeder et al., 2017; Davis et al., 2023; Kieslinger et al., 2018; Von Gönner et al., 2023). Stanifer et al. (2022) evaluated the impact of a CS approach in home radon testing on participants using indicators such as environmental health literacy (knowledge of radon exposure as a health hazard), health information efficacy (ability to search and process radon information), response efficacy (the belief that health threats can be identified via radon testing) and self-efficacy (respondents confidence in their ability to perform home radon testing, contacting a radon professional and hiring a radon professional).

In terms of scientific impacts, various indicators are used to assess the effectiveness of CS projects, including peer-reviewed publications, considerations of data quality, publication of data and results in specific media outlets and online repositories, and the generation of new research topics or new knowledge resources (Davis et al., 2023; von Gönner et al., 2023; Kieslinger et al., 2018). The European Union's Horizon 2020 research project Monitoring Impact of Citizen Science (MICS) include metrics such as citation counts for project publications, impact indices or publication impact factors, support for student dissertations or theses, and strategies for disseminating project outcomes (MICS platform online).

Another significant aspect of assessing the impact of CS projects is the socio-ecological and economic impact, which is measured through indicators such as societal impact, ecological impact, and wider

innovation potential (Kieslinger et al., 2018). These broader societal impacts extend beyond individual participants and scientific outputs, often providing evidence for policy formulation and decision-making.

The learning gains to participants can be situated within the context of learning theories in education. CS initiatives exemplify free-choice learning, where participants pursue research based on personal interests and motivations. For student participants, where the emphasis is on learning by doing, experiential theory of learning comes into play. According to Kolb and Kolb (2009), experiential learning is characterized by acquiring knowledge through direct experience, with reflection on those experiences being crucial. In the context of radon where participants learn how to use radon devices in their homes, this is applicable also to adult participants.

### 3.3 The case of public health risk radon

Radon, a naturally occurring radioactive gas resulting from the decay of uranium in rocks and soil, is odourless, colourless and tasteless (World Health Organization, 2009). Radon gas can enter into buildings, particularly homes, through cracks in the foundation, walls, floors, and other openings. Hence, it can accumulate in high concentrations within indoor environments such as dwellings and workplaces.

Exposure to indoor radon presents a significant health risk, as radon is ubiquitous and is also the main cause of lung cancer after tobacco smoking. Due to the unique characteristics of radon, testing of an indoor radon concentration is the only way to determine associated exposure risks. While some European countries show higher number of measurements of indoor radon and more detailed surveys in high- radon areas (e.g., the Czech Republic, Germany, Switzerland, United Kingdom) in the Digital Atlas of Natural Radiation by the Joint Research Centre (JRC), others have either reduced their annual measurement campaigns or need to update their data (European Commission: Directorate-General for Energy et al., 2023). The voluntary participation of citizens to measure radon in their homes represents a main challenge to achieve significant radon testing rates (Mc Laughlin et al., 2022). Furthermore, mitigation rates remain low (Hevey et al., 2023). A recent empirical study conducted in Slovenia, involving a representative sample of respondents from low, middle and high radon risk areas (N = 1012), suggests that radon interventions should go beyond enhancing awareness, knowledge and risk perception. Instead, they should evoke emotions, share personal stories, highlight successful mitigation cases, include testimonies from affected individuals and incorporate positive social norms to inspire more people to engage in testing and mitigation measures (Perko et al., 2024). CS could be recognised as such intervention.

CS has emerged as one of the promising means to increase radon testing and mitigation rates (Hahn et al., 2020; Martell et al., 2021), thereby safeguarding public health. Through CS, citizens may become empowered to actively participate in research, motivating them to take protective action. To explore this potential, the European funded research project RadoNorm established a “CS Incubator.” At the onset of this initiative, four CS pilot projects were developed across four European countries, France, Hungary, Ireland, and Norway over a period of 6 months to test a CS model for radon testing and mitigation in Europe (Martell et al., 2024).

Having implemented these pilot projects, a fundamental question that arises and which is the core focus of this article is: how effective have these four CS projects been in generating impacts and what criteria and indicators can help to better evaluate the impact of CS projects? Such evaluations are crucial to assist policymakers in improving CS funding schemes, enhancing project management practices, and, most importantly, extracting lessons for future CS initiatives (Kieslinger et al., 2018). This is particularly important in CS projects in the field of radon, as these projects address an important public health issue and comprehensive evaluations are rare (Martell et al., 2021).

### 3.3.1 Method: data collection and analysis

For this study, we conducted a non-systematic literature review on CS impact evaluation which is presented in the results section and we utilised the four RadoNorm CS pilot projects to test and improve the indicators of the evaluation framework. Qualitative techniques of semi-structured interviews and content analysis of project reports served to test and improve the evaluation framework. The interviews included both participants and coordinators (who are also researchers) of the four CS pilot projects and hereafter referred to as researchers. We employed protocols tailored to each specific group of interviewees, that is, researchers, adult participants, and student participants. The interview protocol was pre-tested with an adult and a young adult. Purposive sampling was utilized to select participants for the interviews, with inclusion criteria being all individuals involved in the CS project, regardless of their level of activity. Participation in the interviews was voluntary, and was communicated to potential participants via email. Prior to the interviews, participants completed an informed consent form, which provided details regarding the use of the results, assured participants of their anonymity and informed them of their right to terminate the interview at any point without explanation. A total of nine interviews were conducted with eleven people, in accordance with the minimum requirements for interviews as stipulated by Vasileiou et al. (2018). This ensured representation from both participants and researchers. Two of these interviews were conducted jointly with two researchers and two students respectively. The interviews were conducted in English, French, and Hungarian with interview questions relating to the role of citizen scientists and researchers, their experiences and recommendations for CS. The English and Hungarian interviews were carried out online, whilst the interview in French was conducted via telephone due to the participant's technological limitations. The interviews in French and English were conducted by some authors of this article. The Hungarian interview was conducted by an external researcher not related to this project but with experience in scientific research. The interviews were conducted between late November 2023 and early February 2024, with durations ranging from 35 min to slightly over an hour. The interview transcripts were then coded deductively in the NVivo software based on the indicators presented in Supplementary Tables S3-S5. Peer debriefing with an experienced qualitative researcher was used for research validity.

## 3.4 Results

### 3.4.1 Developing the evaluation framework

The evaluation framework was developed based on the systematic review by Martell et al. (2021), and a non-systematic review of CS impact evaluation and was tested and improved using the RadoNorm CS projects. Hence, the framework takes stock of the works of Kieslinger et al. (2018), Martell et al. (2021), Phillips et al. (2018), Von Gönner et al. (2023), Wehn et al. (2021). The framework proposed assesses the impact of CS in the field of radon on five dimensions, enabling evaluation of both outcome and process level: 1) scientific, 2) participants, 3) wider societal impact, 4) learning gains to researchers and 5) process evaluation. With outcome-based evaluation, the goals of activities or projects, the benefits to participants, and recipient of results are assessed whereas in process evaluation, the operational strengths and weaknesses of activities or projects are identified (Kieslinger et al., 2018).

The sustainability of CS projects is not explicitly addressed as a separate dimension or indicator since the assessment questions across the five described dimensions already encompass this type of evaluation. According to the European Commission (2006), “a project is sustainable when it continues to deliver benefits to the project beneficiaries and/or other constituencies for an extended period after the Commission's financial assistance has been terminated.” The evaluation of sustainability proposed by the European Commission in higher education cooperation projects follows two main criteria: 1) diversity and intensity of either activities/outputs or outputs and outcomes maintained, developed and/or

disseminated and 2) intensity or enlargement of the cooperation. Therefore, the sustainability of CS projects can be assessed based on project results and the continuity of the outcomes and the visibility of results beyond the conclusion of initial funding.

For the scientific dimension (Table 3.1), indicators relate to scientific publications, the science outcome in terms of whether the CS project answers a specific research question, data and data management, generation of new knowledge and other means of sharing the CS project. Additionally, we incorporate the scientific productivity indicator, a composite measure evaluating scientific output over a defined period. Scores are assigned based on weighted criteria, with an overall score ranging from 30, indicating lower productivity to 42, reflecting higher productivity (see MICS platform for details). In terms of disseminating outcomes through alternative channels other than scientific publications, a score of 0 suggests no dissemination while a score of 6 signifies strong dissemination efforts (MICS online tools).

Table 3.1 Scientific dimension to evaluate the contribution of CS in the field of radon.

| Indicators                        | Assessment questions                                                                                                                                                                                                                                                                                                                                                                                                               | References                                                                |
|-----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------|
| Scientific publications           | Are data and results of the CS project published in scientific journals? How many scientific papers have been published?<br>Are journal publications open access?<br>Are citizen scientists acknowledged in research publications?<br>Are citizen scientists co-authors in research publications?                                                                                                                                  | Kieslinger et al. (2018), Martell et al. (2021), Von Gönner et al. (2023) |
| Science outcome                   | Does the CS project answer a specific research question?<br>Does the project inform a policy or a decision on radon management?                                                                                                                                                                                                                                                                                                    | Kieslinger et al. (2018), Martell et al. (2021)                           |
| Data and data management          | What data have been generated?<br>Are the data available on online repositories?<br>Is the data appropriately archived for future analysis? Is the data openly accessible?                                                                                                                                                                                                                                                         | Martell et al. (2021), Von Gönner et al. (2023)                           |
| Generation of new knowledge       | What new research questions or proposals have been generated?                                                                                                                                                                                                                                                                                                                                                                      | Kieslinger et al. (2018)                                                  |
| Scientific productivity indicator | How many publications resulted from the citizen science project? How many citations did the project publications receive?<br>What is the impact index or highest impact-factor of the publications? Did the CS project contribute to or result in any student dissertations?<br>What other means were used in sharing the outcomes (conference, webinars, television, newspapers, social media, workshops, community talks, etc.)? | MICS platform                                                             |

Table 3.2 Participant dimension to evaluate the contribution of CS in the field of radon.

| Indicators                                                        | Assessment questions                                                                                                                                                                                                                                                                                                                                                                                                                                             | References                                                                 |
|-------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| Behaviour and ownership                                           | Did citizen scientists: carry out radon testing and/or mitigation? Intend to carry out mitigation in the event of radon levels above the stipulated reference levels? Re-test after carrying out mitigation? Express or demonstrate a sense of ownership or stewardship through participation?                                                                                                                                                                   | Kieslinger et al. (2018), Phillips et al. (2018)                           |
| Knowledge gained on radon                                         | Did citizen scientists: express or demonstrate an increase in the knowledge gained on radon/on health effect of radon? Demonstrate radon awareness through the project?                                                                                                                                                                                                                                                                                          | Kieslinger et al. (2018), Phillips et al. (2018), Von Gönner et al. (2023) |
| Knowledge gained on radon mitigation strategies and professionals | Did the citizen scientists express or demonstrate any knowledge gained on radon mitigation strategies/professional mitigation companies/preventive measures?                                                                                                                                                                                                                                                                                                     |                                                                            |
| Skills gained                                                     | Did citizen scientists: explore or search further information on the topic of radon? Learn how to use radon devices or was training offered to participants on how to use radon detectors? Demonstrate skills such as asking questions, experimenting, exploring, observing, predicting, drawing conclusions? Learn how to use any scientific instrument or was training offered to participants on how to use any scientific instrument? Gain any other skills? | Kieslinger et al. (2018), Phillips et al. (2018), Von Gönner et al. (2023) |
| Interest in science                                               | Did citizen scientists: show or demonstrate an interest in radon-related science? View their participation in the citizen science project as contributing to science and supporting scientific work? Recommend such activities to others? Show or demonstrate an interest in any other related science topics?                                                                                                                                                   | Phillips et al. (2018)                                                     |
| Motivation and engagement                                         | Did participation raise motivation, self-esteem and empowerment of citizen scientists? Did citizen scientists express or demonstrate a willingness to continue or participate in similar activities?                                                                                                                                                                                                                                                             | Kieslinger et al. (2018), Phillips et al. (2018)                           |
| Self-efficacy                                                     | How confident are participants about their ability to (e.g., perform radon testing, use a DIY approach to radon mitigation, engage mitigation professionals, participate in CS projects)?                                                                                                                                                                                                                                                                        | Phillips et al. (2018)                                                     |
| Perceived experiences on non-participants attitudes               | What are the attitudes of non-participants to the topic of radon that citizen scientists interact with? Do non-participants perceive radon as a risk/radon exposure as a health threat to themselves? Are non-participants aware about radon? Are they likely to conduct a radon test? How much do non-participants know about radon?                                                                                                                            |                                                                            |

On the participants' dimension (Table 3.2), we assess indicators that gauge the learning outcomes and empowerment experienced by participants, including aspects such as behaviour and ownership, knowledge, skills, interest, motivation and engagement, and self-efficacy. With respect to behaviour, we focus on observable actions related to radon testing, mitigation, re-testing and intention to mitigate, as intention serves as a determinant of actual behaviour according to the theory of planned behaviour (Ajzen, 2011). Regarding knowledge gains, we assess citizen scientists' knowledge and awareness of radon in general, and on mitigation strategies whereas skills relates to scientific enquiry and the use of scientific devices such as radon detectors. Interest in science assesses the degree to which participants assign relevance to the topic of radon, and science in general in terms of their contribution to scientific work and whether they recommend CS to others. We assess motivation as an outcome and not initial motivation to participate in the CS project (see Phillips et al. (2018) for the distinction). Motivation and engagement encompass increased motivation via participation in the CS project, self-esteem and empowerment of citizen scientists. The final indicator on this dimension is self-efficacy, assessed as participants' confidence to engage in radon testing and mitigation, engage mitigation professionals and general ease of participation in the CS project. It is also crucial to evaluate participants' learning or experiences regarding non-participants' attitudes toward scientific topics of relevance to society, such as the topic of radon. Similar to the indicators used to gauge participants' interest and attitudes towards the scientific topic of study, comparable metrics should be applied to assess participants' learning about the attitudes of non-participants with whom they discuss the CS project.

At the broader societal impact level (Table 3.3), indicators assess the collective capacity of participants to achieve shared objectives, the influence of the CS project on policy formulation and decision-making processes, and the use or development of new technologies such as the assembling of low-cost sensors for radon testing. Our research emphasises the importance of including public outreach of CS projects, which can occur at three levels or circles of influence: a) the participants themselves; b) the individuals directly influenced by the participants, including family members (e.g., the number of individuals within households), friends, and colleagues and c) the general public through press coverage and the overall visibility of the project (Van Brussel and Huyse, 2019).

Table 3.3 Societal and innovation dimension to evaluate the contribution of CS in the field of radon.

| Indicators              | Assessment questions                                                                                                                                                                                                                                                                                                                                                         | References                   |
|-------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|
| Collective capacity     | Did the CS project contribute to the collective capacity of participants in achieving common goals?                                                                                                                                                                                                                                                                          | Kieslinger et al. (2018)     |
| Political participation | Does the project impact on policy processes and decision making (e.g., agenda setting or data contribution for policy evaluation)?                                                                                                                                                                                                                                           |                              |
| New technologies        | Did the CS project foster the use or development of new technologies?                                                                                                                                                                                                                                                                                                        |                              |
| Economic impact         | Did the CS project generate any economic or competitive advantage?                                                                                                                                                                                                                                                                                                           |                              |
| Public outreach         | How many citizen scientists were engaged in the CS project? What is the household size of citizen scientists?<br>Did the citizen scientists discuss the CS project with friends and colleagues? How many people did the citizen scientists talk to about the CS project?<br>How were project outcomes disseminated to the general public?<br>How visible was the CS project? | Van Brussel and Huyse (2019) |

Our research proposes to include a critical assessment of the learning impact on researchers, such as project management skills, communication and interpersonal skills and the development of expertise in CS research (Table 3.4). Hence, at the outcome level, the learning gains for researchers are assessed based on the benefits to researchers (e.g., increased visibility, improved communication skills) and expertise gained in CS, for example, through literature reviews and CS workshops.

In the process evaluation (Table 3.5), indicators include the level of engagement of citizen scientists (e.g., involvement of citizens in the different stages of the research process), feedback mechanisms (e.g., feedback to citizen scientists on project outcomes), legal and ethical considerations (e.g., informed consents, ethical approvals), funding programmes (e.g., availability of funding for CS projects), collaboration and synergies (e.g., with schools, experts from other disciplines, corresponding programmes such as energy saving, air quality, cancer or anti-smoking programmes, new European Bauhaus initiative, etc.), and the evaluation of CS projects, whether conducted internally or externally. This dimension of process evaluation can be linked to support mechanisms (as referred to by Von Gönner et al., 2023) essential for ensuring the effective implementation and success of CS projects.

### 3.4.2 Impact of the RadoNorm citizen science pilot projects on science

A number of scientific publications were produced from the CS pilot projects, a year after their closure (see Supplementary Table S1). The CS project in Hungary has also supported a PhD thesis in Physics in the area of science education.

Each CS project sought to answer a specific research question in radon risk management, as illustrated in Table 3.6. All of these questions have been answered to a large extent.

In addition, all four CS projects generated valuable data in the form of guidelines, communication supporting materials, and toolkits aimed at enhancing awareness and knowledge about radon, particularly concerning testing and mitigation measures. These resources and Do-It-Yourself (DIY) toolkits were co-created through various workshops and meetings with citizen scientists. These are adaptable for future CS projects. The data generated from the pilot projects (Table 7) will be accessible online via the RadoNorm toolbox on STOREDB, ensuring open access in accordance with European open science policy and European General Data Protection Regulation. The French data is openly accessible online on STOREDB. Besides journal publications, various communication channels were utilized to effectively disseminate project outcomes including conferences, meetings, webinar, project designed websites or webpages, Facebook, project reports and deliverable. Through the use of a diverse array of communication channels, the projects significantly expanded their outreach and amplified the impact and visibility of their research.

Table 3.4 Learning gains to researchers to evaluate the contribution of CS in the field of radon.

| Indicators                         | Assessment questions                                                                                                                                                                                                  | References                                      |
|------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|
| Benefits to researchers            | Did scientists/researchers: benefit from participating in citizen science? learn from the project? Did the CS project: improve the societal relevance of researchers' output? increase visibility of the researchers? | Martell et al. (2021), Von Gönner et al. (2023) |
| Tools for building expertise in CS | Did researchers gain expertise in CS?                                                                                                                                                                                 | Von Gönner et al. (2023)                        |

Table 3.5 Process dimension to evaluate the contribution of CS in the field of radon.

| Indicators                                 | Assessment questions                                                                                                                                                                                                                                                                                                                                                                                                                                                    | References                                      |
|--------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|
| Collaboration and synergies                | Did the CS project collaborate with other initiatives at the (inter-) national level to enhance mutual learning and gains?<br>Did the CS project link to experts from other disciplines?<br>Did the CS project collaborate with local or national authorities? Did the CS project collaborate with any high school(s)?                                                                                                                                                  | Kieslinger et al. (2018)                        |
| Funding programmes                         | Are there adequate funding programmes for CS?<br>What do researchers think on the availability of funding for CS projects (internal or external, local or international)?                                                                                                                                                                                                                                                                                               | Von Gönner et al. (2023)                        |
| Legal and ethical considerations           | Are there clear principles and guidelines regarding legal and ethical issues? Is there a code of research integrity to which all actors must adhere?<br>Is there a research ethics consent form available (e.g., informed consent, parental consent)?                                                                                                                                                                                                                   | Martell et al. (2021)                           |
| Level of engagement                        | Are participants actively involved in the different stages of the CS project? Did the citizen scientists participate in the problem definition?<br>Did citizen scientists participate in developing the research question?<br>Did citizen scientists participate in the choice or design of the research method? Did citizen scientists gather data?<br>Did citizen scientists analyse or interpret data?<br>Did citizen scientists communicate or disseminate results? | Martell et al. (2021)                           |
| Feedback to participants                   | Are citizen scientists informed of how their data are being used? Are citizen scientists informed of the research outcomes?<br>Are citizen scientists informed of the policy or societal outcomes?                                                                                                                                                                                                                                                                      |                                                 |
| Internal or external CS project evaluation | Is the scientific output of the CS project evaluated? Is the participant experience evaluated?<br>Is the CS project evaluated internally by coordinators? Is the societal or policy impact evaluated?<br>Are independent external evaluators engaged to evaluate the CS project?                                                                                                                                                                                        | Martell et al. (2021), Von Gönner et al. (2023) |

In terms of generating new proposals, the project in Hungary is ongoing and has enhanced the low-cost sensors to improve user- friendliness and to enable real-time data publication via Wi-Fi connection. Additionally, there are plans to expand radon measurements to multiple sites. Furthermore, based on the experiences of the pilot projects, RadoNorm funded and helped to launch six new CS projects on radon risk management consisting a diverse network of citizens in six European countries. In France, the project team has submitted a proposal, in collaboration with partners, addressing radon in response to an open call. The proposed project emphasises a CS approach, facilitated by the achievements of the RadoNorm CS pilot project. Indeed, “we propose a project, we build a consortium with the partner,

and the project is underpinned by the citizen science approach and we could not have done that without having achieved the RadoNorm CS pilot project” (CO4). Further initiatives, albeit without concrete timelines include replicating the pilot project in a different region of France and transforming the online guide into a smartphone application with the assistance of computer-literate citizens.

For the final indicator on scientific impact in the framework, we estimated the scientific productivity indicator of the CS projects, as detailed in Supplementary Table S2. The projects achieved a score of 22, comprising 10 points for publications and citations, and 12 points for other communication and dissemination efforts related to the CS project. The score of 12 for the latter indicates successful sharing of the project, extending learning beyond the project’s scope. However, the score of 10 for publications suggests a limited contribution to scientific literature.

Table 3.6 Research questions, objectives and participants of the RadoNorm pilot CS.

| CS pilot project country | Research questions                                                                                                                                                    | Objectives                                                                                                                                                                            | Participants                                                                                                                                                                                                 |
|--------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| France                   | How to improve a self-assessment guide for radon building diagnosis to enhance the implementation of remediation measures?                                            | To test and improve an existing online self-evaluation guide for radon diagnosis                                                                                                      | The group of citizen scientists consisted of 4 residents who participated in the 2020–2021 radon measurements campaign, along with 2 individuals from local public bodies knowledgeable about radon          |
| Hungary                  | Can an ordinary CO <sub>2</sub> meter, prevalent in classrooms post-COVID-19, be effectively combined with radon measurements to achieve a more liveable environment? | To test whether it is feasible to develop an affordable toolkit measuring several air quality and radiation components, including radon, CO <sub>2</sub> , particulate matter and CO. | 18 students from three high schools in Budapest and Székesfehérvár                                                                                                                                           |
| Ireland                  | Can citizens successfully mitigate their homes using a do-it-yourself toolkit that they have co-created, and does this approach increase the rate of mitigation?      | To create a DIY toolkit to increase radon mitigation rates                                                                                                                            | 19 citizens completed radon testing, and 9 discovered radon levels above the 200 Bq/m <sup>3</sup> reference level in their homes. 7 citizen scientists participated in the DIY toolkit co-creation workshop |
| Norway                   | What are the barriers to radon remediation and how to overcome them?                                                                                                  | To overcome barriers to radon remediation?                                                                                                                                            | 8 citizen scientists participated in the first workshop, 97 participated in the measurement campaign and 32 in the final meeting of the CS project                                                           |

### 3.4.3 Impact of the RadoNorm citizen science pilot projects on citizen scientists learning and empowerment

The learning and empowerment outcomes of the pilot projects are illustrated showing both self-reported data and researchers' perspectives from the interviews. Analysis of self-reported evidence reveals that the most frequently reported impact was behavioural action, entailing testing, mitigation, or both, followed by skill acquisition, increased interest in science, motivation and engagement, enhanced radon knowledge, understanding of mitigation techniques, and self-efficacy. However, a more substantial reference to knowledge is apparent when improved radon knowledge and knowledge of mitigation are considered together. The pilot CS project served as their initial exposure to information about radon for some citizen scientists; "I had never heard of radon. It was the first time I'd taken part in this type of activity. I could take part in similar radon projects in the future, why not? I learnt that radon can be dangerous to human life" (PA9).

The first action on behaviour motivated by the CS projects is indoor radon testing. The self-reported evidence in Supplementary Table S3 shows that all participants interviewed revealed action on radon testing. Testing for radon was carried out either for a week or 12 weeks. In Norway, the CS project launched a radon measurement campaign between October 2022 and January 2023, aimed at addressing the relatively low rates of radon testing in a priority area. A total of 97 households were successfully recruited to participate in the radon measurement campaign (Tomkiv and Anjum, 2023), marking a significant increase in testing activities within the targeted municipality. By encouraging homeowners to test their homes for radon in a high priority area, the campaign effectively stimulated a change in behaviour towards radon testing.

These efforts not only raised awareness about the importance of indoor radon testing but also contributed to a greater understanding of radon exposure risks within the community.

The outcomes reveal that participants in the CS projects engaged in various actions following radon measurements in their homes. While some undertook mitigation measures when concentrations exceeded reference levels (e.g., sump and fan, either through DIY approach or with professional assistance, Dowdall and McKittrick (2023)), others adjusted their ventilation behaviours (Olahne Groma, 2023). Furthermore, a citizen scientist with high radon concentration levels who had not yet taken action expressed intention to do so: "we have talked about it that we want to do something there, for example to have the air outside or something" (PA7). To ensure the effectiveness of mitigation actions in safeguarding themselves and their families, participants undertook re-testing. "We repeated the measurements and analyses and the radon level dropped" (PA9). Another participant explained: "as we were like with a monitoring because I had the monitor there at that stage, but I was really surprised to see that the results were literally immediate that the level kind of dropped down" (PA6). Indeed, this participant continues to monitor indoor radon levels with an active radon monitoring device as of the time of the interview: "But I still use that monitoring device as well. Just out of curiosity, even though it's always given me good news which is low levels and, in the greens, so it's nice to know" (PA6). For citizen scientists interviewed, participation in the CS project induced a feeling of responsibility and ownership. "I think at least the ones that took part, they feel more responsibility, to also telling others about it, and talk about it to the people you have around you" (PA7); Whether it's colleagues or family or friends or something like that as well, just advising them like a little bit you know to get the 3-month monitoring done and kind of go from there. It's nice to know. Ohh yeah, kind of like an advert or advocate for it now. Just passing on the good news you know" (PA6); "I discussed this project with my friends and convinced them to take action" (PA9); "I was very excited to participate in this project, and talked about it a lot" (PA10).

Participants gained skills related to scientific inquiry, the use of scientific devices, and other practical skills such as using Excel, data analysis and developing communication skills as shown in Supplementary Table S3. In the interviews, scientific inquiry skills were mentioned as frequently as the use of scientific devices. Self-reported evidence of these learning gains included statements such as: “I kind of did a bit of research, then I knew obviously getting the ground sump with the extraction fan on it would be the only way to do with the particular design and year of build of my house” (PA6); “I’ve already like for example made adjustments to the speed levels of the fan, things like that, and then just retest it to see if there would be, you know, maybe an increase if I slow the speed of the fan down too much. But you know, it was fine, and it had obviously a positive impact as it reduced the noise down a little bit more but not risking kind of with increasing radon levels so which was good, it’s more just experimenting you know” (PA6); “Our students started to watch on internet as well to try to find which sensors will be good” (PA8).

On motivation and engagement, participants expressed how their involvement in the CS projects boosted their self-esteem and empowered them to take protective measures against high radon levels. All participants interviewed expressed their willingness to participate in similar future activities, indicating that their involvement in the pilot projects has increased their motivation to engage in such endeavours. Some statements include: “So we understood that it was a bigger project in Europe as well, yeah, and that’s, of course, that’s very good, yeah. That’s very nice to know that, I can participate in that, that I can be a little important” (PA7). “It’s interesting to be when it’s especially as I say, something that’s kind of so new as well umm you kind of feel you are first, first, to get a little bit of extra knowledge” (PA6). “I suppose just Peace of Mind, really. And I think that’s the biggest thing, just to know that it’s something that’s been ruled out and I know exactly how it’s done. So, if there’s any, ever any replacement parts, for example on the fan or anything like that, I know exactly how everything was done because I was there” (PA6). “I find this experience very useful as it helps me to decide where to go for further studies in which direction. Now I can see if research is for me or not” (PA10). “I am interested in receiving more information on other projects in Europe or other studies of the same style” (PA9).

In terms of self-efficacy, participants across all four projects demonstrated their ability to perform radon testing with radon measurement devices. In Ireland for instance, citizen scientists felt highly confident in explaining mitigation procedures to others following the DIY co-design workshop (Dowdall and McKittrick, 2023). The interviews revealed citizen scientists’ efficacy in mitigation efforts and their ease of participation in the CS projects. However, the references to this indicator were limited in number. Regarding interest in science, it was observed that a predominant interest was expressed towards the scientific topic of radon, among others.

The CS projects implemented a variety of activities that either raised awareness on radon and/or improved radon knowledge among participants. These activities included educational workshops, distribution of informational materials, public meetings, workshops and hands-on training sessions. Through active engagement in these activities, citizen scientists gained a deeper understanding of the risks associated with radon exposure and learned effective mitigation strategies. For example, students in Hungary received comprehensive education on radon. Public information meetings covered topics such as radon exposure risks, the importance of mitigating elevated radon levels, and DIY measures for reducing radon in homes (Dowdall and McKittrick, 2023; Tomkiv and Anjum, 2023). Some meetings also addressed strategies to encourage community involvement in radon mitigation efforts (Tomkiv and Anjum, 2023). Participants also gained knowledge on mitigation, and how to engage with mitigation professionals and firms for assistance. This is supported by self-reported evidence as presented in Supplementary Table S3, indicating significant learning gains among citizen scientists. Some testimonials related to learning gains as reported by citizen scientists include:

“What touched me the most was the fact that I had never heard of radon but it can have an impact in the home and on the health of many people. This impacted me. And that it is the second cause of lung cancer, after tobacco” (PA9).

“Now we know much more about radon and understand better its risk” (PA10).

“I suppose, not really knowing until I found out a little bit more about it, because not knowing, I suppose the effects and that this can have on people as well” (PA6).

“Not a lot as regards health. If I would have known for example from a building point of view. But as regards the effects or anything like that of radon, I wouldn't have known anything about, like, you know, levels of how harmful it is or isn't, you know” And so yeah, kind of help both ways. Yeah, learn a little bit more, I say what I heard health wise, but also from a building point of view, what you can do to improve it in the house and to reduce levels” (PA6).

“We also had that meeting in our town as part of the project and we talked about which mitigation firms you can contact and they could say that it was OK, because many people want to remediate and have money, just money, but they do not know which firm to contact” (PA7).

“We would open the window, build in ventilation systems, and if the level is very high, we would put thicker base for the houses” (PA10).

#### 3.4.4 Wider societal impact of the RadoNorm citizen science pilot projects

The pilot CS projects have yielded broader societal impacts, including the collective capacity of participants to achieve common goals, provision of tools and data for agenda setting and decision-making, development of simple technologies and generation of economic benefits. For instance, the radon guide in Norway is readily accessible to the public through the website of the intermunicipal company (Tomkiv and Anjum, 2023), enhancing its potential to increase radon awareness, knowledge, and mitigation strategies among visitors. Additionally, *the homeowners' association* in Norway is willing to share the guide with all of their about 200,000 homeowners (ibid). Professional unions, such as contractors' union in Norway would like to improve the radon information guide by incorporating perspectives from professional contractors. It is worth noting that the CS project in Norway revealed a lack of trust in actors who offer radon mitigation (Tomkiv and Anjum, 2023) and in response to this, the head of the radon contractors' union in Norway has expressed an interest in writing an article for distribution to all union members with the aim of addressing issues of public trust concerning contractors and propose strategies for improving trust levels to enhance mitigation rates and stimulate business growth. Thus, the CS data generated in Norway serves as a critical driver for facilitating extensive discourse and informed decision-making within the area of radon mitigation among industry stakeholders.

In Ireland, there has been a notable increase in the sale of DIY toolkits for radon mitigation. This surge in sales can be attributed, at least in part, to the widespread dissemination of the DIY mitigation video on YouTube, which has been viewed over 7,500 times within a year (as of 16th May 2024). Additionally, referrals to the video by sales personnel promoting such toolkits may have further contributed to this trend. The rise in sales of these mitigation toolkits has potential significant economic benefits, as it not only boosts revenue for suppliers but also generates income for those involved in the distribution and retail sectors of such materials. One respondent highlighted the impact of the mitigation video on consumer behaviour, stating: “We have come a long way with aids that are helping, and I believe the video has been watched quite a lot, and I think there's an increase in the sales of the do-it-yourself kits. So, the sales of the do-it-yourself kits, I know there's one contractor when he sells them, he directs people to the video” (CO1).

In Hungary, student citizen scientists created low-cost sensors capable of measuring various air quality components simultaneously. This initiative can be classified as the development of new technology. Through this process, students not only developed, set up, and tested the toolkit, fostering the creation of user-friendly technologies, but also gained valuable hands-on experience, an opportunity they may not have otherwise had due to limited financial opportunities (Olahne Groma, 2023). A first-hand account of this states, “And of course they don’t learn anything about the instrumentation, the measurements setup, and how to build and so on” (CO3). Furthermore, through the collaboration with high schools, particularly on the public health issue of radon, the CS project has the potential to reach a broader population, including the families, friends, and relatives of participating students and teachers. This equips them with information to engage in discussions at local, municipal, regional, or national levels on such issues, particularly in a population with low knowledge and awareness about radon that needs to be increased and deepened as highlighted in the National Radon Action Plan (2018) (Martell et al., 2022). Subsequently An example of the potential societal impact is illustrated by this statement: I think for me the easiest to reach citizens is through teachers who work with students, so it’s an easy, easy way for communication and reaching people” (CO3).

The CS project in France facilitated the dissemination of a wealth of information from experts to citizens and vice versa. This enabled citizens to comprehend radon information effectively, thereby contributing to the enhancement of the radon mitigation guide. Consequently, the technical findings yielded were both constructive and comprehensive, offering valuable insights to guide short and medium-term modifications and developments of the radon mitigation guide (Andresz and Schieber, 2023). Additionally, the CS project did prompt a reassessment of the communication strategies of experts, advocating for more adaptable messaging and enriched pedagogical approaches in future initiatives (Andresz and Schieber, 2023). As such, the data generated by the CS project would be instrumental in facilitating the framing of future radon messaging to citizens. Moreover, the CS project improved the guide’s efficacy in fostering post-measurement action against radon exposure, amplifying its visibility and audience reach (Andresz and Schieber, 2023), thus emphasizing its broader societal impact.

### 3.4.5 Learning outcomes of the coordinators of the RadoNorm citizen science pilot projects

Across all four CS projects, the coordinators have gained insights from the public perspective regarding radon and mitigation, broadening their understanding of the challenges and beliefs shaping attitudes towards radon. Indeed, one respondent said: “getting this like knowledge from other actors, knowledge that we don’t think about or finding out about the challenges that others are facing that we can’t even imagine because we always look from our own perspective, from our own framing, from academia” (CO2). Another respondent stated: “We expected that the citizens will have this point of view and that point of view and in fact as it is the citizens did not. They had really another point of view” (CO4). By engaging citizens at various stages of the research process, researchers enhance their connection with diverse community groups, thereby potentially expanding their visibility within the academic and public spheres. One respondent mentioned: “we got invited, like we got booked for a conference in November 2023 to come and talk to radon mitigation contractors and I mean others, researchers, people from industry, and representatives of the House Owners Association as keynote speakers” (CO2).

Other learning opportunities and benefits are outlined in Supplementary Table S4. Among them, gaining practical experience on CS had more references, followed by participatory tools for expertise. For three out of the four coordinators, this was their first time coordinating a CS project and they gained knowledge about CS through different means as shown.

### 3.4.6 Process evaluation for citizen science in radiation protection

Across the four projects, collaborations were multifaceted, involving partners at local, national, and international levels. While three projects focused primarily on local and national collaborations, the French project engaged with another country (Switzerland). However, regardless of the scope, the outcomes of these collaborations hold significant potential for informing radon mitigation strategies and enhancing communication approaches.

Moreover, all partners serve as pivotal facilitators in disseminating the project outcomes (Martell et al., 2022). In addition, collaborations with other programmes, such as energy efficiency, anti-smoking, indoor air quality or cancer programmes was lacking, replicating the results from evaluating national radon action plans in EU Member States which indicate no systematic links with relevant corresponding programmes (European Commission: Directorate- General for Energy et al., 2023).

Ethical advice or approval was diligently obtained for data collection across all four pilot projects, either from the RadoNorm Ethical Committee or external sources like universities or national research centres. Citizen scientists mostly completed forms including expression of interest and consent forms for the research itself and or for the use of citizen scientists' pictures, ensuring compliance with data protection regulations (Martell et al., 2022). Confidentiality was maintained through the non-publication of internal project documents, and personal data were either not collected or anonymized to safeguard privacy (Martell et al., 2022). Citizen scientists assumed diverse roles across the pilot projects, engaging in a range of activities. Depending on the objectives of the pilot projects, citizen scientists collaborated in co-creating either measurement toolkits, mitigation toolkits, or strategies and aims of the CS project. In all the CS projects, participation was voluntary and the form of participation was the choice of citizen scientists. A summary of their self-reported level of engagement is provided in Supplementary Table S5. Across all four countries, citizen scientists contributed by collecting radon measurements and promoting awareness of the CS projects to others. In most cases, citizen scientists were also involved in recruiting citizens to conduct radon testing in their homes. For instance, in Norway the first 20–30 participants for the project's radon measurement campaign were recruited by the citizen scientists (Tomkiv and Anjum, 2023).

Only student citizen scientists were involved in data analysis and disseminating project results.

Regarding feedback in the context of radon measurements, citizen scientists received their results and possible action to mitigate in case of high levels (Martell et al., 2022). Furthermore, the results of the CS project in France, including recommendations and suggestions for the guide, along with findings from CS applications, were compiled into slideshows and text documents throughout the project (Andresz and Schieber, 2023). These outcomes were presented to participants during a wrap-up meeting in July for validation and feedback.

On funding, reactions were mixed. While some researchers during the interviews thought it could be easy to access funding for CS projects, others thought otherwise. Overall, funding was considered necessary for sustainability of CS projects. RadoNorm provided funding for the CS projects which was essential for the implementation of the projects.

The evaluation of CS projects varied internally, with assessments conducted either by citizen scientists or researchers themselves, while one project lacked evaluation altogether. For instance, the French pilot administered a feedback questionnaire to citizen scientists, guided by RadoNorm partners and existing literature (Phillips et al., 2018). This questionnaire included a tailored section designed to gather insights from diagnostic experts, a group from which feedback was typically scarce (Andresz and Schieber, 2023). In one CS project, internal evaluation was absent, while in two others, project coordinators conducted self- evaluation, documenting lessons learned and or the extent to which project objectives

were met (Supplementary Table S6). In Norway, coordinators justified their reliance on self-evaluation, citing the impracticality of formal internal assessments by participants due to the project's adoption of an escalator engagement model (Skarlatidou and Haklay, 2021). This model provided citizen scientists with the autonomy to choose activities aligned with their interests and needs (Tomkiv and Anjum, 2023).

Supplementary Table S7 provides the summary of the evaluation results for each country on all dimensions and indicators.

### 3.5 Discussion

The study provides evidence of the measurable impacts of CS projects in the field of radon on all three outcome dimensions: scientific, participants and socio-ecological dimensions as outlined in (Kieslinger et al., 2018). It also aligns with the framework of public participation in scientific research by Shirk et al. (2012). The study demonstrates the feasibility of measuring the impacts of CS projects across scientific, participant, and societal dimensions at the outcome level but also process evaluation at the process level. The framework presented herein and the suggested improvements, by incorporating researchers' learning gains as an additional dimension coupled with other dimensions, offers a structured approach to assess CS projects' effectiveness, particularly in radon research and radiation protection. Thus, this research contributes valuable insights applicable not only to radon-specific projects but also to similar research within related fields.

The key findings on the scientific dimension reveal that the research questions of the pilot projects predominantly centred on radon mitigation, attempting to address a relevant gap in the current literature whereby most research on radon has focused on testing rather than mitigation (Mc Laughlin et al., 2022). Nevertheless, radon testing was performed by participants as that is the first measurable action to determine concentration levels and assess the subsequent need for mitigation measures. Regarding co-authorship, citizen scientists were acknowledged in project results and publications but were not included as co-authors. This finding has already been critically assessed by Martell et al. (2021), as it seems standard practice. A data management plan was crafted for the pilot project in France. This aspect holds particular importance as data management practices in CS projects are frequently overlooked and remain scarce (Bowser et al., 2020; Hansen et al., 2021). It is worth noting that the RadoNorm CS pilot projects have resulted in the funding of new CS projects focusing on radon, the generation of a new proposal in response to an open call, and the emergence of new research questions. Even though the CS projects have not yet yielded many scientific publications, their scientific publications are significant, considering that the CS projects resulted in two publications within the time frame of a year after the end of the CS projects. In fact, Follett and Strezov (2015) also observe that most CS projects need time to result in scientific publications.

In line with findings from other studies, the CS pilot projects increased participants' knowledge, awareness and informed behavioural actions such as testing and mitigation. For instance, the French pilot project emphasised its contributions to increasing participants' understanding of radon risks in homes, building diagnosis, mitigation strategies, as well as fostering scientific inquiry skills and behaviour change (Andresz et al., 2023). Similarly, in their assessment of a CS approach to home radon testing in four rural Kentucky counties, Stanifer et al. (2022) observed an increase in environmental health literacy among citizen scientists. Additionally, Brossard et al. (2005) conducted a study on the Birdhouse network project, demonstrating a significant impact on participants' understanding of bird biology. In general, the CS projects motivated participants to change their personal behaviour regarding testing, ventilation and other mitigation measures, resulting in increased radon testing and mitigation in priority areas. This demonstrates the potential of the CS approach to significantly contribute to radon

risk management. This finding is consistent with Hahn et al. (2020), where radon testing rates were reported to have increased through the engagement of citizen scientists in research.

Furthermore, in Ireland, 6 out of 9 citizen scientists carried out mitigation as compared to a previous finding where 1 out of 5 did so (Dowdall et al., 2016). Citizen scientists were supported financially to mitigate, with no cost to them together with the support of a radon contractor as compared to the former case mentioned (Dowdall et al., 2016) where private householders bore the cost of both testing and mitigation (Martell et al., 2024). This suggests the necessity of further assessing mitigation rates in CS projects with and without funding support to determine whether participation drives mitigation actions or if financial support plays a significant role. Additionally, it underscores the importance of governmental or CS project support for mitigation actions.

In general, the findings regarding participant gains are consistent with the outcomes of the VegeSafe and DustSafe CS programs (Isley et al., 2022), which focus on metal concentrations in homes (specifically soil in gardens and dust from vacuum cleaners) and were evaluated within the framework of Kieslinger et al. (2018). For instance, the CS results align with those of Isley et al. (2022), who demonstrated that involvement in these CS projects led to various benefits for participants, including increased knowledge, changes in personal behaviour, a feeling of responsibility or ownership toward the project, and motivation to participate in similar or future studies. Notably, participants also expressed the benefit of peace of mind from understanding the levels of metal concentrations and measures to mitigate elevated levels, as reflected in the current findings on radon.

Besides these traditional measures of skills gained as commonly measured in CS impact evaluations, citizen scientists also expressed gaining other skills such as using Excel, creating diagrams, analysing data, and communicating effectively with others.

The involvement of students in radon-related research offers a 'learning by doing' experience, serving as a pivotal educational process with the capacity to extend its impact to a wider audience through these students. Indeed, schools are viewed as potential multipliers where teachers and educators assume crucial role of intermediary experts by engaging as participants, facilitators and motivators in CS initiatives (Kloetzer et al., 2021). For instance, Tsapalov et al. (2020) assessed a CS approach in a radon survey, RadonTest online system project in Israel that actively engaged students. Their findings indicate that involving students through a CS approach in radon research significantly enhances the dissemination of crucial information regarding radon risks across populations and administrations at various levels. Furthermore, incorporating schools into CS activities holds particular significance, as it not only cultivates scientific literacy among students but also has the potential to motivate or increase interest in STEM (science, technology, engineering, and mathematics) careers (Heggen et al., 2012). The involvement of students and local communities also fosters inclusivity in CS beyond the typical well-educated, affluent individual audience (Ruiz-Mallén et al., 2016).

On the influence of the CS projects on policy making, not much has been achieved yet, similar to concerns raised by Von Gönner et al. (2023), even though the pilots resulted in wider societal impacts as previously mentioned in the results. Particularly in comparison to other CS projects like the Evict Radon CS project which contributed in forming the essential rationale for legislative action, in the form of the first ever Radon Awareness and Testing Act: Bill 209 (Martell et al., 2021) or the CS study on insect biomass trends that led to the adoption of the new German Insect Protection Law, BMUV 2019 (Von Gönner et al., 2023). Nonetheless, not much CS results have been incorporated into political decision making until now (Hecker et al., 2018; Nascimento et al., 2018; Von Gönner et al., 2023). Furthermore, the testimonial regarding the Irish project underscores the perceived impact of the mitigation video on the increased sales of DIY kits, with sales personnel and or contractors actively recommending the video as a supplementary resource. While these qualitative insights offer valuable

anecdotal evidence suggesting that the CS project may have contributed to the observed rise in sales of mitigation toolkits thereby, generating economic impacts, hence, contributing to a wider societal impact. It is important to note that other contributing factors may also be at play. Therefore, attributing the hike in sales solely to the CS project may not be supported by rigorous evidence. Further research is necessary to thoroughly investigate the precise influence of the video on consumer behaviour and its overall contribution to the mitigation toolkit market in Ireland. Nevertheless, it is worth noting that the availability of radon information (e.g., radon guide, mitigation toolkit, low-cost sensors toolbox) on the internet via the CS projects increases the accessibility of this information, which is often limited in radon-prone areas, especially at the local level (Perko and Turcanu, 2020).

The analysis of project reports, and interviews with both participants and researchers, indicate a notable discrepancy in the level of engagement among citizen scientists, particularly adult participants. For instance, project reports reveal that the CS approach utilized was either participatory or extreme CS according to the CS typology of Haklay (2013). In both approaches, data analysis and dissemination of project results are key aspects. Nonetheless, adult participants were not involved in disseminating project results, with this task predominantly undertaken by student participants in the case of Hungary. Moreover, students have exhibited greater involvement in analysing radon measurement results compared to their adult counterparts. This observation however aligns with Weinstein (2012) assertion that the involvement of citizen scientists often falls short of full participation in the complete scientific process. The active engagement of high school students in multiple stages of the research process highlights the necessity for providing adequate training to citizen scientists, especially in the context of radon research. The absence of such training not only limits the range of research activities in which participants can effectively engage but also underscores the importance of equipping them with the necessary research skills. In fact, Von Gönner et al. (2023) note that it is common for CS projects to prioritize the development of specific data collection skills, such as species identification, rather than explicitly engaging participants in the principles of scientific research. Indeed, our analysis highlights participants self-efficacy in using radon detectors to collect data on radon concentration levels, be it passive or active detectors. Therefore, to truly engage citizens beyond mere data collection in CS and enhance their scientific skills, concerted efforts should be made to offer comprehensive training on the scientific process to citizens. Such efforts are crucial for effectively involving them in CS and maximizing their contributions to research activities. Furthermore, similar to the findings of Stanifer et al. (2022), citizen scientists exhibited confidence in their ability to contact radon mitigation professionals and or carry out mitigation, either independently or with contractors.

Based on the results of the CS projects, their potential or achieved sustainability becomes evident through the outputs and impacts they generate. These outputs and outcomes can be readily adapted to future CS endeavours or similar projects. For instance, the DIY mitigation video developed in Ireland has been successfully adapted by the new RadoNorm CS project in Slovakia.<sup>4</sup> Additionally, the dissemination of project outcomes through diverse channels and the ongoing CS initiative in Hungary, despite the conclusion of its initial funding, underscore the sustainability achieved or potential thereof of the CS projects. Indeed, one of the criteria outlined by the European Commission (2006) for assessing project sustainability is the extent to which results are maintained, developed further, or disseminated following the end of funding. Consequently, project results serve as a solid foundation for sustainability and other Horizon 2020 projects, such as PERFORM (Vizzini et al., 2017) and BuildERS (Kajganovic et al., 2022), have applied this criterion in their sustainability plans, demonstrating its significance in ensuring the enduring impact of such initiatives.

Table 3.7 Data generated by the RadoNorm CS projects.

| CS project country | Examples of data generated                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| France             | Leaflet, data management plan, questionnaire about the building self-assessment guide, Protocol to compare the building self-evaluation guide with an expert (see full list in Andresz et al. (2023))                                                                                                                                                                                                                                                                                                                      |
| Hungary            | Low-cost sensor toolkit, technical documentation in Hungarian and easy to read English, radon measurements                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Ireland            | Communication flyers, Do It Yourself mitigation toolkit [information for householders about radon remediation options; materials needed to install an active radon sump to remediate a home (fan, pipe, cover, etc.), installation instructions leaflet, an instructional YouTube video Reducing Radon – A Do It Yourself Solution, <sup>5</sup> professional support of a registered radon contractor, two passive detectors, citizen scientist feedback], radon measurements and mitigation data, feedback questionnaire |
| Norway             | Communication flyers, webpage, radon information guide <sup>6</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                        |

Given the variability, subjectivity, and lack of standardization in internal evaluation methods observed across the CS projects within the RadoNorm initiative (Supplementary Table S6), this article's objective is justified in addressing the inherent challenges posed by inconsistent evaluation methodologies. Through the development of a standardized framework, this study aims to aid CS projects in the evaluation of project impacts and facilitating easy comparison of these impacts across diverse CS initiatives. Notwithstanding, the diverse nature of CS projects and their varying aims of impact assessments (Wehn et al., 2021), the framework presented in this study can be tailored to accommodate different CS projects, particularly in the field of radon.

### 3.6 Conclusion

This research proposes a holistic and comprehensive evaluation framework to help improve the outcomes and processes of CS projects. It develops and tests different evaluation dimensions and indicators in the form of questions. Five dimensions, enabling evaluation at both the outcome and process levels, are elaborated: 1) scientific impact, 2) participant engagement, 3) wider societal impact, 4) learning gains for researchers, and 5) process evaluation. To test the developed indicators for practical application, four CS projects related to public health protection from radon were evaluated. Content analysis of project documents and semi-structured interviews were used to respond to all questions (indicators). The limited number of projects evaluated hinders the generalisation of the results. However, the evaluation results help identify strong and weak points in the projects, providing insights for improving future CS initiatives in radon research.

All four evaluated projects focused on indoor radon, a carcinogenic natural radioactive gas. The evaluation demonstrated that CS projects in this field can improve radon testing and mitigation rates, as well as increase knowledge and awareness about radon. These projects can provide new scientific knowledge, empower participants in decision-making, and have a societal impact on affected communities. However, the evaluation also identified challenges, such as initial motivation of citizens, sustainability constraints, limited scientific impact and the influence of project results on policy-making and legislation. Further research is needed to assess the impact of CS projects in the five defined dimensions, particularly on the behavioural and socio-cultural effects on participating citizen scientists

and their decision-making in mitigating efforts. Refining the approaches to evaluating CS initiatives can enhance the design of future CS projects and support policy and research in this field.

The framework presented in this study can be tailored to accommodate various CS projects, particularly those addressing environmental and public health risks.

### 3.7 Ethics statement

The studies involving humans were approved by Trinity College Dublin's ethics committee; Norwegian centre for research data (NSD) and RadoNorm Ethical Committee. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Written informed consent was obtained from the individual(s), and minor(s)' legal guardian/next of kin, for the publication of any potentially identifiable images or data included in this article.

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### 3.9 Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fenvs.2024.1436283/full#supplementary-material>

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## 4. Evaluation of the Citizen Science RadoNorm incubator

Radon exposure poses a significant public health risk, yet authorities often struggle to engage residents in high-risk areas to test and mitigate radon levels in their homes. Traditional top-down approaches have shown limited success in motivating citizen participation, thus is expected, that bottom up approach through citizen science could be beneficial. This chapter aims to assess the effectiveness of citizen science (CS) approaches in enhancing radon measurement and mitigation efforts across Europe, with a focus on community engagement and impact, conducted by the RadoNorm Citizen Science Incubator. To evaluate their impact, a mixed-methods approach was used, including computer-assisted web interviews with 231 citizen scientists, interviews with seven researchers, and group discussions with ten CS coordinators. The citizen science evaluation method developed by Hoedoafia MA, Martell M and Perko T (2024)<sup>19</sup> has been used. (Presented in the previous chapter)

Results show that through the citizen science initiative, over 800 citizens and 57 research organizations across the EU collaborated on various CS projects, ranging from crowdsourcing to extreme citizen science. Pilot CS projects in France, Hungary, Ireland, and Norway informed the design of an open call, resulting in the selection and funding of six CS projects in Italy, Poland, Portugal, Slovakia, Slovenia, and Spain. The results show that these projects employed diverse CS methodologies to address specific community needs and improve radon awareness, measurement, and mitigation strategies. The study highlights the successful outcomes of these projects, including the development of new radon dosimeters, innovative mitigation techniques, increased public awareness, improved local policies, and expanded school curricula.

The findings demonstrate the potential of citizen science to enhance public engagement, improve risk communication, address research and scientific gaps and contribute to more effective radon protection strategies.

The table below (Table 4.1) presents the evaluation results of citizen science projects in Italy, Poland, Portugal, and Slovakia, integrated into the RadoNorm Incubator. The assessment covers the impacts across scientific, participant, societal, and researcher dimensions at the outcome level, as well as process evaluation at the process level.

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<sup>19</sup> Hoedoafia MA, Martell M and Perko T (2024) Evaluating citizen science projects: insights from radon research. *Front. Environ. Sci.* 12:1436283. doi: 10.3389/fenvs.2024.1436283

Table 4.1 Summary of CS project results for each country on all dimensions and indicators

| Dimension                   | Indicators<br>(including<br>survey items)                           | Italy                                                                                                                                                 | Poland                                                                     | Portugal                                                                   | Slovakia                                                                                                                                                                                          |
|-----------------------------|---------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|----------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Scientific <sup>8</sup> (R) | Scientific publications including proceedings and book of abstracts | Not yet                                                                                                                                               | 2 abstracts                                                                | 3 abstracts                                                                | Not yet                                                                                                                                                                                           |
|                             | Science outcome                                                     | The project had a clear research question which was successfully answered.                                                                            | The project had a clear research question which was successfully answered. | The project had a clear research question which was successfully answered. | The project had a clear research question which was successfully answered.                                                                                                                        |
|                             | Products, Data and data management                                  | radon measurements, radon distribution map, communication leaflets, video (all data freely available on <a href="#">Source</a> International website) | radon measurements, communication materials (e.g. leaflets), videos.       | radon measurements, communication materials (flyers, posters)              | radon measurements <sup>9</sup> , tailor-made radon remediation projects,<br>leaflets, roll-up banner, FAQ with answers<br>Video (all data freely available on <a href="#">NatuRadon</a> website) |

| Dimension    | Indicators<br>(including<br>survey items) | Italy                                                                                                                                                            | Poland                                                    | Portugal                                                                                 | Slovakia                                                                                                                                    |
|--------------|-------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------|------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
|              | Generation of new knowledge               | Communication established with other environmental regional authorities in two regions, Piedmont and Lombardia, to co-design some future projects of CS on radon | new research questions and new proposal                   | project replication in 3 Portuguese districts: Guarda, Viseu and Coimbra from Sept. 2024 |                                                                                                                                             |
|              | Scientific productivity indicator         |                                                                                                                                                                  |                                                           |                                                                                          |                                                                                                                                             |
|              | Questionnaire                             |                                                                                                                                                                  |                                                           |                                                                                          |                                                                                                                                             |
| Participants | Behaviour and ownership                   | radon testing (147 homes, 37 rooms in 4 schools, and 47 workplaces = 231 <sup>10</sup> tests). (R)                                                               | radon testing (homes, classrooms, soil, & water samples,) | radon testing in 300 dwellings                                                           | radon testing, 47 dwellings (passive detectors in 91 rooms), 34 dwellings (active detectors in 126 rooms), change in ventilation behaviour, |

| Dimension | Indicators<br>(including<br>survey items)                                     | Italy                     | Poland                                                                           | Portugal                                                                                                                         | Slovakia                                                                              |
|-----------|-------------------------------------------------------------------------------|---------------------------|----------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
|           |                                                                               |                           |                                                                                  |                                                                                                                                  | intention to mitigate – at least<br>3 citizens (R)                                    |
|           | knowledge<br>gained on<br>radon                                               |                           | radon knowledge, radon<br>awareness (R)                                          | radon knowledge,<br>radon awareness (R)                                                                                          |                                                                                       |
|           | knowledge<br>gained on radon<br>mitigation<br>strategies and<br>professionals | mitigation strategies (R) |                                                                                  |                                                                                                                                  | mitigation strategies,<br>tailored cost calculation for<br>mitigation<br>measures (R) |
|           | Skills gained                                                                 | use of radon devices (R)  | skills of inquiry; use of<br>scientific instruments,<br>communication skills (R) | skills of inquiry, use of radon<br>devices, scientific literacy, data<br>analysis skills, and critical<br>thinking abilities (R) | use of passive & active radon<br>devices (R)                                          |

| Dimension                             | Indicators<br>(including<br>survey items)           | Italy                                        | Poland                                                                                    | Portugal                                                                                   | Slovakia                                                                                              |
|---------------------------------------|-----------------------------------------------------|----------------------------------------------|-------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|
|                                       | Interest in science                                 |                                              |                                                                                           |                                                                                            |                                                                                                       |
|                                       | Motivation and engagement                           |                                              |                                                                                           |                                                                                            | self-esteem (participation in competition), (R)                                                       |
|                                       | Self-efficacy                                       |                                              |                                                                                           |                                                                                            |                                                                                                       |
|                                       | Perceived experiences on non-participants attitudes | -                                            | -                                                                                         | -                                                                                          | -                                                                                                     |
| Societal & Wider innovation potential | Collective capacity                                 | contributing to a radon distribution map (R) | contributing to co-creating content for public dissemination of project on TikTok. health | the project brought people together to achieve common goals. environmental stewardship (R) | contributing to co-creating radon mitigation projects, empowering citizens to take protective action, |
|                                       | Political participation                             |                                              |                                                                                           |                                                                                            |                                                                                                       |

| Dimension                                  | Indicators<br>(including<br>survey items) | Italy                                                                                                                                           | Poland                                                                                      | Portugal                                                                                                     | Slovakia                                                                                                                               |
|--------------------------------------------|-------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
|                                            | New technologies                          |                                                                                                                                                 | low-cost sensors capable of measuring radon and other air quality components simultaneously |                                                                                                              |                                                                                                                                        |
|                                            | Economic impact                           |                                                                                                                                                 |                                                                                             |                                                                                                              |                                                                                                                                        |
|                                            | Public outreach                           | 231 citizen scientists, (multiply by average number of household) newspaper articles, project webpage, social media - Facebook & Instagram. (R) | TikTok, conferences, press releases, online magazines, news portal interview (R).           | newspaper articles, project webpage, conferences, social media - Facebook & Instagram. (R + project updates) | 47 citizen scientists (multiply by average number of household)<br><br>project webpage, public exhibitions, conferences, Facebook. (R) |
| Benefits and learning gains to researchers | Benefits to researchers                   |                                                                                                                                                 |                                                                                             |                                                                                                              | None of the core team members had previous experience in participating or managing CS project. Hence, gained knowledge on CS           |

| Dimension                                | Indicators<br>(including<br>survey items)                | Italy                                                                                               | Poland                                           | Portugal                                      | Slovakia                                                                                                                                                                                                                               |
|------------------------------------------|----------------------------------------------------------|-----------------------------------------------------------------------------------------------------|--------------------------------------------------|-----------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                          |                                                          |                                                                                                     |                                                  |                                               | issues, insights from others,<br>communication skills (R)                                                                                                                                                                              |
|                                          | Tools for<br>building<br>expertise in<br>citizen science | via experience of<br>implementing CS projects                                                       | via experience of<br>implementing CS<br>projects | via experience of implementing<br>CS projects | via experience of<br>implementing CS projects                                                                                                                                                                                          |
| Project<br>process/support<br>mechanisms | Collaboration &<br>synergies                             | local & regional authorities,<br>e.g., ARPAT <sup>11</sup> ;<br>collaboration with 4<br>schools (R) | collaboration with a senior<br>high school       | collaboration with 3 high<br>schools (R)      | local authorities (e.g.,<br>collaboration with mayor,<br>(G)) collaboration with<br>Faculty of Wood Sciences<br>and Technology at the<br>Technical University in<br>Zvolen, collaboration with<br>secondary construction school<br>(R) |
|                                          | Funding<br>programmes                                    |                                                                                                     |                                                  |                                               | key for project<br>implementation and meeting<br>goals (R)                                                                                                                                                                             |

| Dimension | Indicators<br>(including<br>survey items) | Italy                                                                                                                                                         | Poland                                                                                                                                                                                                                                                                                                                             | Portugal                                                                                                                                                                                                                                                                                                                                                          | Slovakia                                                                                                                                                                                                                                                                                                                                                                                       |
|-----------|-------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|           | Legal & ethical considerations            |                                                                                                                                                               | parental consent forms (developed in cooperation with the development and marketing department of AHS), managing data protection issues with the use of social media accounts (R)                                                                                                                                                  | compliance with GDPR <sup>12</sup> in all phases of the project implementation, followed best practices and recommendations of the Ethics Committee of Instituto Superior Técnico - University of Lisbon.<br><br>informed consent (R)                                                                                                                             | informed consents - data processing (both citizens and legal representatives of students) and for students participation (legal representatives of students), cooperation agreement - property owners/citizens (R)                                                                                                                                                                             |
|           | Level of engagement                       | participatory science, citizens conducted radon measurements, contributed to a set of data collection as buildings information and radon perception risks (R) | participatory science, a bit of “Level 4 (extreme citizen science) citizen scientists placed detectors, decided on where to collect samples, participated in introductory sessions to gain knowledge on radon, co-analysed measurement results during weekly meetings, and decided on the next steps (where to redo measurements), | extreme citizen science (students), crowdsourcing (volunteers). Student citizen scientists disseminated information about radon, engaged the population to conduct radon measurements, co-developed the research question via meetings and class sections, co-analysing/interpreting data from the results. Other citizen scientists (volunteers) conducted radon | distributed intelligence citizens were involved in the distribution of detectors, conducting radon measurements, evaluation of data from measurements by active detectors by their own decision, evaluation of data from measurements by passive detectors, cooperation with students during the design of tailor-made radon remediation projects, communicating their questions with experts; |

| Dimension | Indicators<br>(including<br>survey items)  | Italy                                                                                                                        | Poland                                                                                                   | Portugal                                                                                                                                                                 | Slovakia                                                                                                                                                                                                                                                 |
|-----------|--------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|           |                                            |                                                                                                                              | disseminated project via TikTok (R).                                                                     | measurements and participated in project public events (R).                                                                                                              | students citizen scientists designed tailor-made remedial projects, disseminated project, (initial plan: ‘participatory science’ which could not be achieved due to lack of time). (R)                                                                   |
|           | Feedback to participants                   | results of radon measurements, wrap-up public event - project outcome. (R)                                                   | results of radon measurements, citizen scientists informed of their data usage via informed consents (R) | results of radon measurements, public local events at each municipality- project outcome. (R); citizen scientists informed of their data usage via informed consents (R) | results of radon measurements, tailor-made remediation projects, final public meeting – project outcome (R); citizen scientists informed of their data usage via informed consents for data processing (citizens & legal representative of students) (R) |
|           | Internal or external CS project evaluation | Internal evaluation – self-evaluation by coordinators. No internal evaluation of satisfaction of the project by citizens (R) | Internal evaluation – Self-evaluation by the coordinators                                                | Internal evaluation – Self-evaluation by the coordinators (R)                                                                                                            | Internal evaluation, self-evaluation by coordinators (R)                                                                                                                                                                                                 |

| Dimension | Indicators<br>(including<br>survey items) | Italy | Poland                                                                            | Portugal | Slovakia |
|-----------|-------------------------------------------|-------|-----------------------------------------------------------------------------------|----------|----------|
|           |                                           |       | self-assessment<br>questionnaire<br><br>self-reflection essays by<br>students (R) |          |          |

Legend:

R = CS project report

S = CS survey questionnaire

G = group/panel discussion with CS coordinators

I = interviews with RadoNorm executive board members.

The table below (Table 4.2) presents the dissemination of scientific results by citizen scientists within the RadoNorm Citizen Science Incubator. Citizen scientists play a key role in not only collecting and analysing data but also in communicating scientific findings to various audiences. Their engagement in dissemination efforts ensures that research outcomes reach a broader public, including local communities, policymakers, educators, and scientific institutions.

Dissemination efforts take multiple forms, ranging from traditional academic publications to more community-centered approaches. Citizen scientists contribute to scientific papers, conference presentations, and reports, ensuring that their work is integrated into the broader scientific discourse. Simultaneously, they engage in outreach activities such as school presentations, public talks, media interviews, and social media campaigns to make radon-related knowledge accessible to non-experts.

The dissemination process is particularly valuable in raising awareness about radon risks, encouraging proactive testing and mitigation measures, and bridging the gap between research and public action. By involving citizen scientists in the communication of findings, the RadoNorm Incubator fosters a more inclusive and participatory approach to science, where research outcomes are not only shared within academic circles but also reach the people who are directly affected by radon exposure.

The table below provides a detailed overview of the various dissemination activities carried out by citizen scientists, highlighting their impact on knowledge-sharing and public engagement.

Table 4.2 Dissemination of the scientific results by citizen scientists in the RadoNorm CS Incubator

| CSP                              | Scientific publication or conference (Journal or editor)                                                                                                         | Public CS dissemination                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Remarks                                                                                                                                                                                                                                                                                                          |
|----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| All CSP (collective achievement) | IRPA <sup>2</sup> 16 (poster)<br>ICRER <sup>3</sup> 2024<br>RadoNorm annual meeting (s), 2023, 2024<br>RICOMET <sup>4</sup> 2023, 2024<br>ERPW <sup>5</sup> 2024 | Panel discussion (hybrid event): “RadoNorm Citizen Science Incubator: meet the coordinators of 7 citizen science projects related to radon”.<br><br>RadoNorm <a href="#">movie</a> and application for EU citizen science prize application<br><br>Online webinar: “webinar from RadoNorm citizen science projects, learn what is ongoing”.<br><br>Webpage: <a href="#">link</a><br><br>RadoNorm news published on web ( N=18 <sup>6</sup> <a href="#">e.g.</a> ) and RadoNorm social media accounts (X and LinkedIn) | Organized as part of RICOMET 2023 (27.08-01.09, 2023, Mol, Belgium) and 2024. 11. June 2024, Ljubljana – Slovenia. <a href="#">Event video</a><br><br>CS project recognized with honorary mention.<br><br>Organized on European Radon Day, 7. November 2023. <a href="#">Event video</a><br><br>RadoNorm website |

| CSP          | Scientific publication or conference (Journal or editor)                                                                                                                                                                                                          | Public CS dissemination                                                                                                                                                                                                                                                                               | Remarks                                                                                          |
|--------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| Italy (R)    |                                                                                                                                                                                                                                                                   | <a href="#">Scientific report</a><br>3 public events<br><a href="#">Project video</a><br>Project report<br>3 newspaper articles ( <a href="#">example</a> )<br>Social media posts (Instagram & Facebook)<br>4 news items on project webpage ( <a href="#">e.g.</a> )<br>Webpage: <a href="#">link</a> | Sep. 2023, Dec. 2023, & Feb. 2024<br><br><br><br><br><br><br><br><br><br>Project partner website |
| Hungary (R)  |                                                                                                                                                                                                                                                                   | Tudományos Diákkörök XXIV. Kárpát-medencei Konferenciája – felhívás                                                                                                                                                                                                                                   | national-level student conference, February 2024, Debrecen                                       |
|              |                                                                                                                                                                                                                                                                   | József Hlavay National Environmental Science and Engineering Student Conference<br>Project report                                                                                                                                                                                                     | national-level student conference, 18 – 19 April, 2024, Debrecen                                 |
|              |                                                                                                                                                                                                                                                                   | Website: <a href="#">link</a>                                                                                                                                                                                                                                                                         | Project designed                                                                                 |
| Poland (R)   | ICRER 2024<br><br>IRPA16 Congress, Orlando (accepted abstract, but no attendance due to financial reasons)<br><br>Copernicus Science Center (25.04.2024)<br>Warsaw Chapter of the Polish Medical Physics Association local scientific conference (12. April 2024) | 12 videos on <a href="#">TikTok</a><br>Newspaper articles<br>High school newsletters<br>PDS <sup>7</sup> fair<br>online magazine “Pamylka”<br>1 news portal <a href="#">interview</a><br>Press releases<br>Project report                                                                             |                                                                                                  |
| Portugal (R) |                                                                                                                                                                                                                                                                   | IAEA Regional Training Course on prevention and mitigation methods for protection against radon exposure in buildings - at Faculdade de Ciências e Tecnologia da Universidade de Coimbra, Portugal;                                                                                                   | 22 – 26 January 2024, Coimbra, Portugal                                                          |

| CSP          | Scientific publication or conference (Journal or editor)                                                                                                                                                                                                          | Public CS dissemination                                                                                                                                                                                                                                                                                                                               | Remarks                                                                                                                                                                                                                                       |
|--------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|              | <p>9th International Conference on Social Sciences and Humanities in Ionizing Radiation Research (RICOMET 2023)-oral poster presentation;</p> <p>IX Congress on Radiation Protection of the Community of Portuguese-Speaking Countries (poster presentation).</p> | <p>C2TN Workshop on Earth Systems, Radioactivity and Cultural Heritage (ESRCH);</p> <p>Public events at municipalities</p> <p>News articles on RadoNorm news and project webpage</p> <p>Project report</p> <p>local news in the school's webpage, news bulletins in local or regional newspapers, information on municipalities webpages</p>          | <p>30. November 2023<br/>Bobadela, Portugal</p> <p>30. August – 1. September 2023, Dessel, Belgium</p> <p>11 – 15 December 2023.<br/>Coimbra, Portugal</p>                                                                                    |
|              |                                                                                                                                                                                                                                                                   | Webpage: <a href="#">link</a>                                                                                                                                                                                                                                                                                                                         | Project partner website                                                                                                                                                                                                                       |
| Slovakia (R) | Student Conference: ENERGOINFO                                                                                                                                                                                                                                    | <p>Public event in Ponická Huta</p> <p>Student's project "Radon in the family house" participation in secondary school professional competition</p> <p>RadonGPS CS project at the CONECO RACIOENERGY 2024 exhibition</p> <p>Online webinar about CS projects: RadonGPS CS project presented (CVTI, Bratislava)</p> <p>European researchers' night</p> | <p>26. April 2024</p> <p>22. March 2024<br/>Placed 2<sup>nd</sup> in self-governing region in Banská Bystrica and 6<sup>th</sup> at the national level</p> <p>20. March – 23 March 2024, Bratislava</p> <p>30. Nov. 2023, Banská Bystrica</p> |

| CSP      | Scientific publication or conference<br>(Journal or editor)                                                 | Public CS dissemination                                                                                                                                                                                                                                                  | Remarks                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|----------|-------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|          |                                                                                                             | 3 Kick-off meetings:<br><br>News articles<br><br>Project report<br><br>Planned dissemination                                                                                                                                                                             | 24. Oct. 2023<br><br><br>29. Sep. 2023<br><br>14. Oct. Ponická Lehôtka,<br>23. Oct. Secondary construction school, 24.<br>Oct. Ponická Huta<br><br>online magazines (Eurostav & Drevársky magazín); Radio Regina, European Researcher's night 2024, one podcast, project results submission for the needs of the National Radon Action Plan of the Slovak Republic. Results to be shared with local, regional, and national authorities, including local governments and Regional Public Health Offices of the Slovak Republic. |
|          |                                                                                                             | Webpage: <a href="#">link</a>                                                                                                                                                                                                                                            | Project partner website                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Slovenia | Two scientific papers in preparation:                                                                       | Project report; project webpages; project events; e-board of ZIK Črnomelj; personal communication; radio coverage; local newspapers, project video in preparation (R)<br><br>Planned dissemination: follow-up event in October 2024 at ZIK Črnomelj, project partner (R) | Project partner website<br><br><a href="#">Example news article.</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Spain    | Planned dissemination:<br><br><a href="#">IV National Radon Congress – Spain</a><br>(planned: 7. Nov. 2024) | Project report<br><br><a href="#">“Citizen Science for radiation measurement” day</a> celebrated by the Nuclear Safety Council (CSN - Consejo de Seguridad Nuclear)                                                                                                      | 8. June. 2023                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |

| CSP | Scientific publication or conference (Journal or editor)                                                                                                                                                                                                                            | Public CS dissemination                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Remarks                                                                                                                                                                                                                   |
|-----|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|     | <p><a href="#">Workshop I+D+i</a> about Radon (Spain) – planned, 11 – 13. Nov. 2023</p> <p>Scientific publication planned in the <i>Journal of the European Radon Association</i> (JERA), <i>Revista RADIOPROTECCIÓN</i> (of the SEPR) and/or <i>Revista Alfa</i> (of the CSN).</p> | <p>Project <a href="#">webpage</a></p> <p>Online meetings/events</p> <p>4 circulars and 2 special announcements</p> <p>in-person activities:</p> <ol style="list-style-type: none"> <li>1. “Jornada Ciencia Ciudadana” at CSN. “El radón y la ciencia ciudadana”.</li> <li>2. Radon Day in Torrelodones.</li> <li>3. Presentation at a speleology seminar in Motril.</li> <li>4. Presentation at the University of Valencia.</li> <li>5. Presentation at Enusa Industrias Avanzadas.</li> <li>6. Presentation at the University of Cantabria, Faculty of Medicine.</li> </ol> <p>Social media (Instagram and Twitter)</p> <p>Ibercivis website</p> <p>Meetings with key stakeholders (pending)</p> | <p>4. Sept. 2023; 5. Oct. 2023; 19. to 23. Feb. 2024 (individual meetings); 11. March 2024</p> <p>8. June 2023</p> <p>7. Nov. 2023</p> <p>14. Nov. 2023</p> <p>17. Nov. 2023</p> <p>24. Nov. 2023</p> <p>1. Dec. 2023</p> |

## Conclusions

The RadoNorm Incubator is a collaborative initiative involving citizens from 10 EU member states, fostering cross-cultural exchange and cooperation. With academic contributions from 22 EU countries, the initiative serves as a hub for the intersection of society, science, and technology. By facilitating transdisciplinary collaboration, the RadoNorm Incubator not only addresses radon-related challenges but also contributes to broader European goals related to sustainability, innovation, and public health.



D6.11. Citizen science for improved and sustainable protection for radon exposure situations

Dissemination level: PU

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[www.radonorm.eu](http://www.radonorm.eu)



Citizen science projects within the RadoNorm Incubator play a crucial role in supporting national authorities in implementing Council Directive 2013/59/Euratom, which requires every EU Member State to establish a national Radon Action Plan. In addition to radon-related initiatives, these projects contribute to wider European objectives, including the European plan to combat cancer, the Green Pact for Growth, and the roadmap for reducing industrial and natural risks.

Furthermore, the initiative is actively engaged in the European Bauhaus Initiative, fostering collaboration among architects, designers, artists, students, and the public. This engagement promotes ideas that integrate aesthetics, functionality, and environmental sustainability, in alignment with the principles of the historical Bauhaus movement.

Citizen science projects within the Incubator have successfully raised awareness about radon, integrated radon education into high school curricula, and addressed construction techniques in several countries. Data and solutions collected by citizen scientists contribute to academic research within the H2020 RadoNorm project. The high scientific quality of these contributions ensures publication on accessible platforms such as Open Europe, strengthening collaboration between researchers and citizen scientists. Community members actively participate in radon testing and mitigation efforts, fostering shared responsibility and ownership in addressing radon-related health risks.

Engagement efforts extend to diverse communities, including libraries in Norway and Ireland, schools in Hungary, Slovakia, Portugal, and Poland, as well as specific villages and regions in Slovenia and Italy. Families and pensioners are involved across all projects, fostering collective action. Recognizing concerns about the climate crisis among younger citizen scientists, the initiative incorporates environmental sustainability measures. While energy-efficient and passive houses are environmentally friendly, they may present challenges related to increased radon concentrations. Citizen scientists, equipped with DIY tools, test different types of houses for radon levels and install mitigation devices to improve indoor air quality. This approach aligns both with environmental sustainability and public health objectives.

Collaboration with national authorities is central to the initiative. In addition to assisting in the implementation of Council Directive 2013/59/Euratom, citizen science projects actively contribute to European efforts to combat cancer, promote sustainable economic growth, and mitigate industrial and natural risks. By integrating scientific research with policy implementation, the initiative aims to address both immediate public health concerns and long-term policy objectives.

Communication and outreach efforts employ various channels, including social media platforms such as TikTok, as well as webinars, blogs, traditional media, local newspapers, and radio stations. Citizen scientists engage with the public in diverse settings, including shopping centres, village intersections, and private homes, ensuring broad dissemination of information.

The RadoNorm Incubator continues to evolve, engaging citizens and researchers at various levels, from crowdsourcing to advanced citizen science methodologies. By fostering inclusive participation and addressing scientific and public health challenges, the Incubator contributes to advancing scientific knowledge and reducing lung cancer cases associated with radon exposure.

## 5. Radon and citizen science

### 5.1 Abstract

Previous studies have shown the value-action gap between radon awareness and actually conducting a radon test or applying mitigation actions. Citizen science, an approach by which the public works together with radon experts during the research process might help to increase not only knowledge but also protective actions. This chapter explores the extent to which citizen science can contribute to increase radon testing and mitigation rates through the analysis of four pilot citizen science projects in the framework of the Horizon 2020 RadoNorm European research project (2020-2025). The citizen science pilot projects were accomplished in France, Hungary, Ireland and Norway in a period of 6 months during the years 2021 to 2022. The results show that citizen science holds promise for promoting radon testing and radon mitigation. Our study contributes to a better understanding of the potential of citizen science in radon management as a means to reduce lung cancer risk.

### 5.2 Introduction

Radon awareness raising campaigns have been one of the main communication tools used to inform citizens about the risks of this indoor air pollutant (Hevey, Perko, Martell, Bradley, Apers, & Rovenská, 2023). The European Basic Safety Standards Directive (BSS) 2013/59/EURATOM also requires European Member States to develop “strategies for communication to increase public awareness and inform local decision makers, employers and employees of the risk of radon, including in relation to smoking” as part of their National Action Plans to address the long-term risks from radon exposure (Perko, Martell, Rovenska, Fojtikova, Paridaens, Geysmans, 2023). In this regard, most of the European Member States have embarked on national radon awareness campaigns to reduce exposure. However, risk communication on radon has mostly focused on testing rather than on mitigation (Laughlin, Gutierrez-Villanueva, & Perko, 2022; Hevey, Perko, Martell, Bradley, Apers, & Rovenská, 2023; Apers, Vandebosch & Perko, 2023).

Research indicates that residents in areas with high radon presence who are aware of its harmful effects may not be concerned about living in a house with elevated radon levels, resulting in a lack of radon testing and mitigation efforts (Poortinga, Bronstering, & Lannon, 2011; Hevey, 2015; Lofstedt, 2019). Perko and Turcanu (2020) and Apers et al. (2023) note that higher levels of stakeholder engagement in radiological protection and in particular, in protection from radon, are needed to address the value action gap observed in radon risk mitigation and increase protective behaviour concerning indoor radon. Citizen science might be one of the tools for engaging the public in scientific research whilst generating scientific data, enhancing knowledge and positively changing their radiation protection behaviour (Santori, Keith, Whittington, Thompson, Van Dyke & Spencer, 2021; Chase and Levine, 2018).

A limited number of CS projects exists in the realm of radiation protection (Kenens, Van Oudheusden, Yoshizawa & Van Hoyweghen, 2020) and in the context of radon, their presence is even scarcer (Martell, Perko, Tomkiv, Long, Dowdall, & Kenens, 2021). Furthermore, the existing CS projects in the field of radon are not registered in CS databases, which makes it even more difficult to identify past or ongoing CS initiatives in this area. The few CS projects in the field of radon have mostly concentrated on radon testing to the neglect of mitigation (*ibid*). Citizen science has proven effective in promoting radon testing, enhancing understanding of radon and boosting confidence in the ability of the citizen scientist to contact a radon

mitigation professional. However, it did not necessarily lead to hiring a mitigation professional or a belief that radon mitigation would effectively reduce the threat of radon exposure (Stanifer, Hoover, Rademacher, Rayens, Haneberg and Hahn, 2022)

The EURATOM Horizon 2020 project RadoNorm has made an important contribution by supporting CS projects in the field of radon and registering them in several CS databases, in particular EU-citizenscience and Scistarter. RadoNorm aims at managing risks from radon and naturally occurring radioactive materials (NORM) exposure situations in order to assure effective radiation protection based on improved scientific evidence and social considerations (Kulka et al, 2022). One of the objectives of the RadoNorm project is to establish a CS incubator for radon priority areas and a network of CS projects to address radon testing and mitigation across Europe. In this regard, RadoNorm partners from France, Hungary, Ireland and Norway developed and tested different models as pilot projects for CS to manage radon risk during a period of six months. This chapter focuses on discussing the potential of CS in radon testing and mitigation, drawing insights from lessons learned in the four RadoNorm CS pilot projects.

### 5.3 Theoretical background

The term CS evolved in the 1990s and became renowned globally in 2012 due to the increased rise in the number of funding schemes, projects and publications (Vohland, Göbel, Balázs, Butkevičienė, Daskolia, Duží, Hecker, Manzoni, & Schade, 2021). Citizen science is a growing phenomenon worldwide and broadly refers to the active participation of citizens in scientific research as researchers, offering non-scientists an opportunity to collaborate with scientists and participate in all stages of the research process (Land-Zandstra, Agnello, & Gültekin, 2021), thereby bridging the wide gap between science and society. CS initiatives also have the potential to increase citizens' trust in scientific outcomes.

Even though citizen scientists have predominantly been involved in data collection and analysis, different citizen science typologies have been developed depending on the level of citizens participation in scientific research. In RadoNorm, we adopt the typologies proposed by Haklay's (2013) which goes from level 1 "crowdsourcing" to level 4 "extreme citizen science" as described in Martell et al. (2021). The table below (Table 5.1) presents the levels of participation applied in the RadoNorm citizen science pilot projects. All four CS projects involved higher levels of citizen participation with France, Hungary and Ireland utilising participatory science and Norway utilised the extreme citizen science approach.

Table 5.1 Levels of citizen participation applied to the RadoNorm citizen science pilot projects

| Levels according to Haklay (2013) |                         | RadoNorm citizen science pilot projects                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|-----------------------------------|-------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Level 3.                          | Participatory science   | <p>In <b>France</b>, participants contributed to improving an existing on-line self-diagnostic tool that helps to identify entry and transfer mechanisms in a building and offer mitigation solutions.</p> <p>In <b>Hungary</b>, high school students in three institutions developed a toolkit consisting of various low-cost measurement sensors to measure air quality, including radon.</p> <p>In <b>Ireland</b>, citizens contributed to co-create a Do It Yourself (DIY) “toolkit” for mitigation.</p> |
| Level 4.                          | Extreme citizen science | In <b>Norway</b> , citizens were approached to define themselves the aim of the pilot citizen science project, the research question and their level of involvement.                                                                                                                                                                                                                                                                                                                                         |

Source: Modified from Martell, Andresz, Dowdall, Fenton, Olahne Groma, Kenens, McKittrick, Perko, Tomkiv, Schieber (2022)

## 5.4 Method

The RadoNorm project proposed a model of CS project in the field of radon and a set of indicators to assess the contribution of a project to radon research based on a scoping review of relevant project in database, systematic review of scientific publications, consultations and interview with radon experts and practitioners as described in Martell et al. (2021). From these, each RadoNorm partners defined the aims and objectives of their pilot project, the collaborating partners and roles, the recruitment strategies and alignment with ECSA 10 principles, which all proved to be different. The main characteristics of the four RadoNorm citizen science pilot projects are described below.

**France:** The focus of the project was the ‘radon building diagnosis’ which is supposed to take place after (high) radon concentrations are measured and prior to mitigation itself. However, this diagnosis is hardly implemented in France. To remedy this situation, the pilot project recruited citizens already aware about radon from Pays Vesoul Val-de-Saône (East of France) to (a) test an existing online self-evaluation guide for radon diagnosis (the guide was the offspring of a former research project funded by Interreg 2017-2019), (b) report on their operational experience through survey and (c) meet with radon/building experts. Citizens contributed to improvements in both form and content of the guide and to ensure that it would be better fit for purpose. Comparison of the guide with experts’ practices in the field provided additional perspectives on building diagnosis. The conclusions from the project were ascertained during a plenary videoconference and the effects of the project for both citizen and expert were surveyed formally (Andresz et al, 2023).

Table 5.2 Roles of the partners in the RadoNorm pilot CS project in France

| Partners                                                                                       | Role in the pilot CS project                                                                                       |
|------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|
| Nuclear Protection Evaluation Center (CEPN)                                                    | Leader, developed the protocol and associated documents; analysed and compiled the data; disseminated the results. |
| High School of Engineering and Architecture Freiburg (HEIA, Switzerland)*                      | Provided expertise on radon/building, participated in the meetings; disseminated the results.                      |
| Centre of Studies and Experience in Risk, Environment, Mobility and Urbanism (CEREMA, France)* | Provided expertise on radon/building, participated in the meetings; disseminated the results.                      |
| Pays de Vesoul Val de Saône (PVVS)                                                             | Assisted with the recruitment of citizens, local organisation; disseminated the results.                           |
| Citizens                                                                                       | Tested the guide, , reported on their operational experience and contributed to the evolutions.                    |

\*Initial developers of the guide.

**Hungary:** The aim of the RadoNorm pilot CS project in Hungary was to test whether it is feasible to develop an affordable toolkit measuring several air quality and radiation components, including radon, CO<sub>2</sub>, particulate matter and CO. This project is driven by the need to address the limited public awareness regarding radon, particularly its correlation with indoor air pollutants and the multiple beneficial effects of mitigation.

Unlike the other three pilot projects which mostly featured adult citizens, the pilot project in Hungary focused on high school students as citizen scientists. Consequently, workshops were first organised for contact teachers from three high schools in Budapest and Székesfehérvár respectively and then for secondary school students of 14 to 18 years old where interested students were invited to become citizen scientists. The eighteen natural science students involved developed a toolkit and tested it through a series of short-term individual measurements at different locations at schools and residences. The results were analysed interpreted in collaboration with teachers and researchers. The pilot CS project included an interdisciplinary component, as students also developed the technical documentation of the toolkit in easy-to-understand English, in collaboration with students of design and communication, who accompanied the development and testing process in addition to helping in the dissemination tasks. The project is disseminated on a student- created website.

Table 5.3 Roles of the partners in the RadoNorm pilot CS project in Hungary

| Partners                                                                       | Role in the pilot CS project                                                                                                                                                                                                                                                                                                 |
|--------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Centre for Energy Research (EK)                                                | Leader, conceptualised and led the assembly process of the tool.                                                                                                                                                                                                                                                             |
| Schools – students                                                             | Volunteers aged 14 to 18 participated in this project-based extracurricular course. Their areas of interest are natural science and communication. First group developed, set up, and tested the toolkit whilst second group wrote the English documentation of the toolkit and designed logo and website for dissemination. |
| Schools – teachers                                                             | Ensuring the conditions of the thematic course, took part in the development work and supervised the students in collaboration with researchers.                                                                                                                                                                             |
| Radiation and air quality measurement experts as well as development engineers | Advised on device selection and contributed to the technical design of the toolkit.                                                                                                                                                                                                                                          |

**Ireland:** The CS pilot project in Ireland aimed to establish a Do-it-Yourself (DIY) toolkit to increase the rate of mitigation. The project was an opportunity for citizens and radon experts to develop a DIY approach for mitigation of private dwellings and to build on the partnership between EPA, the radon contractor, Wexford local authorities, local libraries and Healthy Wexford.

The rationale for this project was the knowledge that despite finding high levels of radon after carrying out a radon test, only one in five householders will carry out mitigation work to reduce these levels (Dowdall, Fenton & Rafferty, 2016). County Wexford in Ireland is a radon priority area where EPA data shows that approximately 500 homes have been tested above 200 Bq/m<sup>3</sup> and 400 of these have not yet been remediated. The main reasons given for not remediating are cost and lack of concern. Householder knowledge of radon mitigation “may not translate into behaviour in the face of psycho-social and financial barriers to action” (EPA, 2019). Using a DIY approach could be a lower cost mitigation for some citizens.

The CS pilot project focused on citizens who had borrowed digital monitors from any of the five Wexford libraries which have loan schemes and had observed high levels of radon. Following a public meeting New Ross library which provided information on the project, attendees were invited to express their interest in taking part in the co-design and testing of the DIY mitigation toolkit and to carry out a three-month radon test. The citizen scientists were recruited once the three-month test confirmed that their levels of radon were above the 200 Bq/m<sup>3</sup> reference level. Their role included: take part in a workshop to co-design the DIY toolkit; test the DIY toolkit in their homes and after testing the toolkit, provide feedback on how it can be

improved. The input of citizen scientists in this CS project was used to generate new knowledge and understanding for the EPA and mitigation experts on supports for householders to help them remediate.

Table 5.4 Roles of the partners in the RadoNorm pilot CS project in Ireland

| Partners                        | Role in the pilot CS project                                                                                                                                                                                                                                                                                                                                                                                |
|---------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| EPA                             | Leader, developed a toolkit with the input of citizen scientists and a radon mitigation contractor; co-ordinated the project locally between the citizen scientists, libraries and radon contractor; reported on the participant testing of the toolkit and finalised it based on the user experience; provided passive radon detectors for participants to carry out pre and post mitigation measurements. |
| Residents (owners of dwellings) | Take part in a workshop to co-design the DIY toolkit; test the DIY toolkit in their homes; participate in 2 meetings and after testing the toolkit, provide feedback on how it can be improved.                                                                                                                                                                                                             |
| Radon contractor                | A radon mitigation contractor registered as such with the EPA <sup>9</sup> . The contractor supported the citizen scientists by providing advice on mitigation; assisted with the mitigation work as required worked on the development of the toolkit with EPA and citizen scientists before and after it was used.                                                                                        |
| Wexford local authorities       | Supported engagement on radon with residents in Wexford County.                                                                                                                                                                                                                                                                                                                                             |
| Wexford local libraries staff   | Administered the loan scheme of digital radon monitors facilitated public meetings for CS recruitment and workshop to co-design toolkit. Provided contact details and completed expression of interest and / or consent forms from residents who had borrowed the digital monitors and observed high readings to EPA.                                                                                       |
| Healthy Wexford                 | Established contacts with their existing networks within the community; promoted the CS project through their social media.                                                                                                                                                                                                                                                                                 |

**Norway:** The Norwegian pilot CS initiative attempted to come as close as possible to 'extreme citizen science' by letting participants define the project themselves and to choose the extent to which they wanted to be involved in the actions identified to improve mitigation. The Norway Pilot CS project took place in Gjøvik municipality, one of the radon priority areas, in collaboration with the intermunicipal public service company Miljørettet helsevern IKS and the City Lab Bylab i Gjøvik. The pilot project began with a public workshop at the local library, where citizens openly discussed barriers for mitigation and what could be done

to get more people to mitigate. Based on the results of the discussion, citizens together with project partners decided that the pilot project will focus on improved public information about radon, radon detection and radon mitigation; better access to radon testing kits; information about professional on radon mitigation and about costs of mitigation; and, information about DIY options for radon mitigation.

Table 5.5 Roles of the partners in the RadoNorm pilot CS project in Norway

| Partners                                                        | Role in the pilot CS project                                                                                                                                                                                      |
|-----------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NMBU/CERAD                                                      | Lead organiser, contact point for the information of the project; analysed the CS project; dissemination of the project through the communication channels of the university (press releases, social media, etc). |
| Gjøvik municipality                                             | Assisted with dissemination of information about the project for the purpose of participant recruitment. Local library hosted the first project workshop.                                                         |
| Miljørettet helsevern IKS intermunicipal public service company | Supported engagement of residents for the RadoNorm citizen science project, assisted with dissemination; recruitment, and practical organization locally.                                                         |
| Residents (individuals)                                         | Define and share the CS project and co-create an information package about radon measurement and mitigation for the local population tailored to answer questions and concerns from the residents.                |

## 5.5 Results

### Conceptualisation of the CS project

As shown in Table 5.1, the RadoNorm CS pilot projects were designed to fit in levels 3 and 4 of Haklay's (2013) typology. Thus, Andresz et al. (2023) argue that the CS project in France differentiated itself from former projects as citizens were at the core of the project in the different steps: in the data collection (the whole radon diagnosis guide was submitted to their analysis), meetings (the words of the citizens and the experts were equal), and overall organisation (the development of the project and the conclusions were entirely based on the citizens' answers and proposals) blurring the usual delineation between experts and citizen. In Hungary, the CS project students not only technically assembled a measurement device but also designed the logo, created the website and helped to develop the technical documentation of the toolkit in easy-to-understand English. The project in Ireland involved citizens in the development of the DIY toolkit by using it in their own home. Their input generated new knowledge and understanding for the EPA and mitigation experts on what supports householders need to help them remediate. Finally, in the “extreme” citizen science model used in Norway citizens themselves defined the barriers to mitigation the project

should focus on, co-created a radon guide, recruited more participants for the measurement campaign and designed public information meeting.

### Recruitment and engagement of citizen scientists

Finding citizens to volunteer to take part in a CS project on radon proved challenging in all four pilot projects. The complexity of the topic and the fact that the start of the projects coincided with the Covid-19 pandemic made recruitment even more challenging.

The CS projects used a range of methods to recruit citizen scientists, from flyers, posters, announcement and articles in local newspapers, radio interviews, specific webpages of the project, press releases, personal letters, social media channels of the partners, emails and phone calls. In some cases, like in Norway, using the established social media channels of the local authorities (i.e. Facebook) had a much bigger impact on recruitment than the physical flyers.

The number of citizen scientists mobilised and engaged in the four RadoNorm pilot projects is shown in Table 5.6. However, it should be bear in mind that the total number of citizens is not necessarily a measure of the success of the CS pilot project.

Table 5.6 Number of citizen scientists involved in the RadoNorm CS pilot projects (without supporting personnel such as teachers or contractors)

|                                | France | Hungary | Ireland   | Norway   |
|--------------------------------|--------|---------|-----------|----------|
| Total n° of citizen scientists | 6 *    | 18      | 9 / 17 ** | 100+ *** |

\*In France, the target set by the project leader was 20 citizen scientists.

\*\*26 potential participants agreed to carry out a 3 month-test following a public meeting, but 19 completed the test. 9 participants had radon levels above the 200 Bq/m<sup>3</sup> reference level and were therefore the target for the CS project.

\*\*\*8 participants took part in the first workshop, 97 participated in the measurement campaign and 32 in the final meeting of the CS project.

Andresz et al. (2023) provide possible (combining) explanations for the low number of participants in the case of France: an opportunistic targeted sampling in a of small size target, a small team of experts, possible erosion of the interest of the inhabitants about radon, the complexity of the topic and cognitive/emotional response to radon.

In Hungary, the cooperation with schools was undertaken at different intensities and the RadoNorm partners adapted to the motivation and possibilities of the teachers and students. Nevertheless, the high level of motivation of the participants have resulted in planning further development and the project is still on-going in the new educational course 2023-2024 with extensions and improved technical solutions.

In Ireland, whilst 40 people attended the first public meeting, 26 attendees completed a form expressing an interest in taking part in the RadoNorm CS pilot project and agreed to carry out a free three-month radon test in their home. Nineteen of these completed the test and received a report with their result. Of these, nine had radon levels above the 200 Bq/m<sup>3</sup> reference level and these were recruited as citizen scientists to co-design the DIY toolkit.

In Norway, the first meeting was attended by five local residents, three representatives from Miljørettet helsevern IKS and three researchers from NMBU, although two additional residents asked to be involved but could not attend that first meeting. In the second online meeting six residents, three of which were new were involved and 2 from Miljørettet helsevern IKS, participated. Free radon dosimeters were offered to 100 households owning and residing in certain target areas of Gjøvik and 97 households signed up to the campaign. A total of 32 participants took part in the final meeting.

The motivations for participating in the different CS projects was varied. Some citizen scientists had a general interest in the radon problem, some were interested in the technical and professional aspects, and some had questions about radon and radon mitigation. The motivations for teachers in Hungary to get involved in the project were linked to the innovative work with students and the resulting publications which are necessary for their career advancement. In France, the motivation of being involved in a European project was appealing for some participants as well as interest on the topic. In Ireland, free expert advice and DIY mitigation kit was a good motivation to become involved in the project, as some had been engaged in the topic of radon over many years but had not been motivated to mitigate. In Norway, some citizen scientists were motivated by the little attention paid to radon in the Gjøvik area and the uncertainty regarding radon being a health problem as one of reasons for being involved in the project.

## 5.6 Outcomes

In all four countries, the citizen science project developed guidelines, supporting materials or toolkits related to increasing information about radon in general or more specifically about radon testing and mitigation. These materials and DIY toolkits were co-created by the participants through different workshops and meetings and in some cases, feedback was provided on how to improve them. In the case of France, where the guide already existed, the modifications proposed by citizens helped to improve it and confirmed its usefulness with regard to fostering action in the radon post-measurement step. The project will help to increase the visibility of this guide.

In the case of Ireland, an increase in the rate of mitigation was observed in the CS pilot project. At 66% this is significantly higher than the rate of mitigation of 22% reported by Dowdall, Fenton and Rafferty (2016). However, it should be noted that this rate of mitigation is based on private householders who paid for both testing and mitigation in their homes whereas for the participants in the citizen science pilot project, there were no costs incurred and they received tailored support from the radon contractor.

## 5.7 Discussion and Conclusion

The RadoNorm CS pilot projects yielded valuable insights into critical considerations when establishing CS projects in radon protection. It became evident that a well-defined project concept, including clear objectives and the potential for active citizen scientist engagement, should be established from the project's inception. Setting achievable goals that contribute to radon measurement and mitigation is paramount. Another crucial

lesson learned pertains to the openness of CS projects, adherence to open science principles, and the careful handling of data protection and personal/sensitive data and ethical principles. The project implementation plan must ensure that planned activities are attainable for citizen scientists while also emphasising an effective strategy to engage citizen scientists. Furthermore, assessing the potential impact of the CS project, including its behavioural and socio-cultural effects on participating citizen scientists and their increased knowledge of radon, is essential. Lastly, assembling a knowledgeable and skilled team with experience in radon related research activities and managing citizen science projects is vital for CS project success.

#### 5.7.1 Role of authorities and researchers in promoting citizen science initiatives on radon

Martell et al. (2021) assessed that the CS initiatives on radon were promoted top-down by researchers and public authorities, unlike CS initiatives in other fields, such as those in the environmental field. Similarly, the RadoNorm CS pilot projects were launched and led either by national authorities (Ireland) or research institutes (Hungary) or universities (France and Norway). However, all these organisations collaborated closely with several local or national partners which was crucial in recruiting participants, disseminating the projects through different channels or providing the technical expertise. The financial support to promote these initiatives has come from the European project RadoNorm. Drawing from the valuable lessons learned from the pilot projects, RadoNorm opened a call for proposals in November 2022 to fund citizen science projects in Europe for a six-month period. Out of nineteen proposals, six projects are funded in Italy, Poland, Portugal, Slovakia, Slovenia and Spain. The promoters of these CS projects include NGOs, universities, national and local authorities, private persons, research institutes and in most cases, consortiums promote and run these initiatives in their regions. These projects make use of different citizen science approaches and are focusing on indoor radon measurements and mitigation (Martell & Perko, 2023).

#### 5.7.2 Radon awareness and awareness of citizen science

Despite the short time frame of the CS pilot projects<sup>20</sup>, it was found that the level of radon awareness and awareness of citizen science increased. The four RadoNorm CS pilot projects raised citizen awareness about radon risks and mitigation actions to reduce exposure. They also created spaces to talk with experts on the topic of radon. At the same time, experts became aware of the opportunities that citizen science may offer in the area of radon management. Experts increased their awareness on the existence of the knowledge and perception gaps between them and citizens and realised of the need to facilitate mutual learning for all parties involved. Nevertheless, there is a need for science-based surveys designed to collect data and empirical evidence to find out why people test (or not) and mitigate (or not) in different social environments and cultures as well as relationship between radon awareness and protection behaviour of residents under radon risk. RadoNorm makes a contribution in this regard by implementing a European RadoNorm behavioural atlas (Perko et al, 2021) in collaboration with radon authorities of 16 European

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<sup>20</sup> The duration of the projects was a maximum of six months, although in some cases, the time frame was shorter (less than five months in France).

Member States. This survey also explores the motivation behind individuals' interest in participating in potential citizen science projects related to radon.

### 5.7.3 Challenges of radon CS projects

One of the challenges in the RadoNorm CS projects is the fact that radon management is a complex topic which makes it difficult for citizens to be motivated to engage. In addition, radon is an indoor pollutant and therefore, a household problem which might not have the same potential for community engagement among stakeholders compared to other environmental issues. In Ireland, by prioritising citizens who had previously borrowed digital radon monitors from libraries, the organisers acknowledged two potential limitations: first, they primarily invited library members as participants, and second, they excluded individuals with no prior awareness of radon.

Similar to other CS projects (National Academies of Sciences, Engineering and Medicine, 2018), the majority of participants in Norway were retired male who typically have more free time compared to other target participants with more diverse ethnic, age or cultural background, such as young homeowners or families with young children.

Implementing effective CS projects proved challenging in all cases due to the significant time required. For instance, one of the planned activities in Norway was to develop videos on DIY mitigation solutions, which did not happen due to time constraints. In Ireland, a limitation arose from the time commitment required of citizen scientists to use a DIY approach to mitigation and carry out one-on-one interactions with the radon contractor. The skillset and the tools necessary for mitigation work were also identified as limiting factors.

### 5.7.4 CS for radon mitigation

The RadoNorm CS pilot projects highlighted was the need to have access to and consultations with mitigation or building professionals before taking any decisions. In addition, the need to offer simple mitigation solutions was also pointed out. Afterall, the low number of professionals interested in undertaking mitigation works, the uncertainty regarding the effectiveness and the real costs are recognized as important barriers to domestic radon mitigation (Hevey et al. 2023).

In line with the findings of Stanifer et al. (2022) our study also underscores the necessity for additional investigations to comprehensively explore the role of citizen science in addressing home radon mitigation.

## 5.8 Acknowledgements

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## 6. Beyond Data Collection: Unravelling the Motivations Driving Citizen Science Engagement

### 6.1 Abstract

A critical question in Citizen Science Projects (CSP) is how to motivate citizens to be highly engaged in the project, beyond data collection. This study identifies the motivations driving individuals to participate in CSP and examines how motivational factors influence the level of engagement among participants. The research utilizes a combination of intrinsic and extrinsic motivations, the citizen science motivation scale, and the level of engagement in citizen science projects. The study evaluates seven projects focused on the indoor air pollutant radon, spanning seven European countries. A mixed-methods approach was applied in 2023 and 2024, combining an online survey with participants engaged in the projects, a group discussion with the coordinators of CSP and analysis of projects documents. The study revealed that when citizen scientists' motivation is primarily driven by intrinsic factors, it fosters higher and more sustained engagement. Those participants seek out novelty, challenges, personal growth, and the pleasure of the experience itself, without the need for external rewards. In addition, altruistic and socially oriented motivations—such as security, benevolence, universalism, and contributing to research—alongside self-direction, emerged as key drivers

of participation across different research stages. In contrast, while extrinsic motivations related to power, personal achievement, and conformity were acknowledged as relevant, they played a less significant role in sustaining engagement. Additionally, contextual specifics of CSPs were identified as important, shaping motivation and levels of engagement.

Keywords: citizen science, level of engagement, motivation, indoor air pollutant radon

## 6.2 Introduction

Despite its potential, citizen engagement in many Citizen Science Projects (CSP) is often limited to specific tasks, such as data collection or sensing (Herzog and Lepenies, 2022; Martell et al., 2021), with fewer involvement of citizens in other stages of the research process, such as formulating research questions, analysing data, interpreting results or disseminating results. One contributing factor to this limitation is low motivation among participants for higher engagement (Ashepet et al., 2024; Wright et al., 2015). This study addresses the following question:

What drives citizens to engage in CSP, and how do these motivational factors influence their level of engagement across different stages of the research process?

“Science for and with society” emphasizes that research and innovation should address societal needs and challenges while actively engaging citizens and stakeholders in the process. It reflects the principles of Responsible Research and Innovation (RRI), which advocate for inclusivity and co-creation among others, to ensure science benefits society as a whole (European Commission, 2012). Consequently, Citizen Science (CS), which engages non-scientists in scientific research, has been increasingly adopted across various fields. By engaging the public in various stages of research, CS empowers individuals in their scientific endeavours (Trumbull et al., 2000), it contributes not only to the advancement of scientific knowledge but also to collective intellectual capacity, the fostering of an open society (Hecker et al., 2018) and the democratization of science (Giardullo et al., 2023; Strasser et al., 2023). In addition, it helps address societal challenges through evidence-based data and informing policy making and decisions (König et al., 2021; Shirk and Bonney, 2018; Strasser and Haklay, 2018). Moreover, it can enhance individual participants' personal development in terms of scientific skills, knowledge gains, and self-efficacy (Den Broeder et al., 2017; Hoedoafia et al., 2024; Phillips et al., 2018).

Understanding the motivations behind engagement in CSP is crucial for several reasons. First, it can guide the design and implementation of projects to better align with participants' values and interests, leading to higher involvement and more effective outcomes (Celino et al., 2021; Heinisch, 2022; Orchard, 2018; Richter et al., 2021). Second, it offers insights into how to maintain long-term engagement, encouraging sustained participation across multiple research phases, from research question formulation, data collection, to analysis, interpretation and dissemination (Celino et al., 2021; Land-Zandstra et al., 2021; Richter et al., 2021). Finally, exploring these motivations can help maximize the broader impact of CS, particularly in addressing critical societal challenges such as environmental health risks.

Research related to an indoor air pollutant – radon, recognised as a significant environmental public health risk, provides a suitable context for examining the dynamics of motivation and level of engagement in CS

initiatives. Radon is an invisible, odourless and radioactive gas which accumulates in indoor environments in specific geological regions and poses a serious health risk to people living in such dwellings, particularly increasing the likelihood of lung cancer (WHO, 2009). World Health Organization recognized radon as the leading cause of lung cancer after smoking. Radon mitigation requires public awareness, knowledge, and action to mitigate its dangers. Most importantly, it relies on motivated property owners who are willing to test their buildings and take necessary technical measures to reduce radon levels. Despite regular interventions by authorities, many European countries continue to report a persistent lack of motivation among residents and property owners to test for and mitigate radon levels in their homes (Hevey et al., 2023; Mc Laughlin, et al., 2022; Perko et al., 2024). This challenge is compounded by the complexity of radon risk management, which lies at the intersection of radiological, technical, socioeconomic, behavioural, and institutional factors (Hevey et al., 2023) offering opportunities for CS to pursue impactful projects. Numerous communication interventions have been implemented by authorities, though many have fallen short of achieving the desired outcomes (Bouder et al., 2021). Research suggests that communication interventions to test and mitigate dwellings need to be tailored to specific population groups and should go beyond enhancing awareness, knowledge and radon risk perception. Effective strategies should evoke emotions, share personal stories, highlight successful mitigation cases, and use personal testimonies from individuals (Apers, et al., 2023; Perko et al., 2024). From this perspective, citizen scientists already play a crucial role in addressing many of these challenges (Martell et al., 2024; Martell et al., 2021) (Hoedoafia, et al., 2024). However, the extent to which citizens remain engaged—beyond initial tasks such as, in the case of radon, placing a dosimeter in their dwelling, leaving it for a designated period, and sending it to a lab afterward—may largely depend on the motivations driving their participation.

This study investigates the motivational factors driving over 700 citizens to participate in the radon-focused initiatives, the European funded RadoNorm CS Incubator, which involves CS initiatives in Hungary, Poland, Slovak Republic, Spain, Portugal, Italy and Slovenia and how these motivations influence the participants' levels of engagement.

We start by introducing a conceptual framework and outlining the motivation-related challenges in the field. Our analysis focuses on the factors that drive motivation for higher levels of engagement in CS. These factors not only shape CS practices but also highlight key considerations that should be integrated into the design and implementation of participatory approaches in similar contexts.

### 6.3 Conceptual framework

Unlike most studies, which often rely on a single theoretical framework, this paper integrates two key theories on motivation: Schwartz's theory of basic human values (Schwartz et al., 2012) and Ryan and Deci's self-determination theory (Ryan and Deci, 2000; 2020), allowing for a more comprehensive analysis of participant motivations.

According to Ryan and Deci (2000), being motivated implies being “moved to do something”. Motivation can be defined as the internal drive or force that moves an individual to take action. A person lacking the desire or stimulus to act is considered unmotivated, while someone who is energized and activated to achieve a goal is described as motivated (Ryan and Deci, 2000:69). The Basic Human Values theory (Schwartz, 1992; 2012) has been widely used to study motivations across various fields. The original Schwartz theory (1992) identified ten basic motivational values, which were later expanded to 19 values in a refined model

(Schwartz, 2012). These motivational values are organized into four broad categories of higher-order motivations: a) openness to change, b) self-transcendence, c) conservation, and d) self-enhancement. These categories are further grouped into two higher-order clusters, reflecting either a personal focus (openness to change and self-enhancement) or a social focus (self-transcendence and conservation). These values are organized along two main axes where values like self-direction and stimulation (openness to change) are contrasted with values like security, tradition, and conformity (Schwartz, 1992, 1994, 2012). Motivational values focused on personal success and dominance (self-enhancement) such as achievement and power, are contrasted with values focused on concern for others and the environment (self-transcendence), such as universalism and benevolence (Schwartz, 2012; Levontin et al, 2022). Hence, Schwartz's theory suggests that these values are related to each other in a circular continuum. Therefore, values that are adjacent on the circle are more compatible, while values on opposite sides of the circle tend to be in conflict. For example, self-direction and stimulation are compatible, but they conflict with conformity and tradition, which emphasize stability and following social norms (Schwartz, 2012). At the highest level of Schwartz's motivational continuum are four overarching categories: growth and anxiety-free values at one side of the circle, and self-protection and anxiety-avoidance values at another side (Schwartz, 2012). These categories distinguish whether values are pursued to avoid anxiety such as security or to foster a state of anxiety-free motivation, such as benevolence. Similarly, values may serve self-protective purposes like power or promote expansion and growth, like in universalism (Schwartz, 2012). A questionnaire is typically used to measure these values where respondents rate how much each of them motivates their decision to participate.

In the context of CS, Schwartz's theory has been adapted and extended to better capture the specific motivations of participants in these projects. One such adaptation is the Citizen Science Motivation Scale (CSMS) developed by Levontin et al. (2022), which is utilized in the present study. The CSMS incorporates both theory-driven categories based on Schwartz's universal human values and data-driven categories derived from previous research on CS. In total, the CSMS consists of 15 motivational categories and 58 items.

In self-determination theory (SDT), Ryan and Deci (2020) distinguish between intrinsic and extrinsic motivation types on the basis that motivation arise from different reasons or goals that prompt actions. According to them, intrinsic motivation refers to engaging in an activity because it is inherently enjoyable, interesting, or satisfying. Hence, the drive comes from within the individual, and the activity itself is the reward. Therefore, people motivated intrinsically often seek out novelty, challenges, personal growth, and the pleasure of the experience itself, without the need for external rewards. Extrinsic motivation involves performing an activity to achieve a separable outcome, such as a reward or the avoidance of negative consequences. This motivation comes from external factors, like earning money, receiving praise, or gaining recognition, rather than from the inherent satisfaction of the activity (Ryan and Deci, 2020). In summary, intrinsic motivations are driven by internal (personal) satisfaction or personal fulfilment, while extrinsic motivations relate to external rewards or pressures, such as financial incentives, and recognition. Understanding this distinction is crucial for exploring the different motivational drivers that influence participation in CS projects.

### 6.3.1 Motivation to participate in Citizen Science Projects

Citizens participate in CSP for different reasons (Tiago et al., 2017; Van Dien and Fuchs, 2023; Ashepet et al., 2024). Understanding the factors that drive people to engage in or disengage from CS is crucial for those aiming to leverage CS effectively, as it offers essential insights for designing successful recruitment and retention strategies (Ashepet et al., 2024; Wright et al., 2015). The primary motivation to participate in CSP can vary depending on the topic or focus of the project (Golumbic et al., 2020; Golumbic et al., 2023). For instance, contributing to science and environmental protection are primary motivators in environment-focused CSP (Alender, 2016; Etter et al., 2023; Lotfian et al., 2020; Maund et al., 2020). In app-based CSP reported by Land-Zandstra et al. (2016) participants were motivated to contribute to scientific goals and a desire to learn about project topics. In health-related CSP reported by Lehman et al., (2020), social connectedness, personal learning and making a difference in the community were common motivations (Table 6.1).

Table 6.1 Motivation to participate in citizen science projects

| Reference             | Motivations to participate in CSP                                                                                                                                                                                                | Topic/focus of CSP |
|-----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|
| Asingizwe et al. 2020 | Curiosity, desire to learn new things, help researchers, and willingness to contribute to malaria control.                                                                                                                       | Malaria            |
| Alender, 2016         | Help the environment/community and contribute to scientific knowledge.                                                                                                                                                           | Water quality      |
| Berghen et al. 2024   | Initially gain knowledge, social interactions, and environmental concern for others. Sustained participants are older, with stronger sense of moral obligation.                                                                  | Agriculture        |
| Beza et al. 2017      | Depending on the country, motivation was the desire to contribute to scientific research or sharing information. Around half of the farmers expected incentives (e.g. agronomic advice, capacity building, and seed innovation). | Agriculture        |
| Celino et al. 2021    | Self-direction, benevolence, and universalism. The least motivators were conformity and power.                                                                                                                                   | Planets/Universe   |
| Diethei et al. 2021   | Collective rather than egoistic motives.                                                                                                                                                                                         | Covid-19           |
| Etter et al. 2023     | Contribution to science, interest in the topic, and nature protection.                                                                                                                                                           | Environment        |

| Reference                  | Motivations to participate in CSP                                                                                                                      | Topic/focus of CSP         |
|----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|
| Frensley et al. 2017       | Interest in the environment and in protecting a local natural resource.                                                                                | Environmental conservation |
| Hvenegaard, & Fraser, 2014 | Helping, learning, and meeting like-minded people.                                                                                                     | Marine species             |
| Golumbic et al. 2020       | Worry, education and outreach, environmental action, personal interest, and opportunistic engagement.                                                  | Air quality                |
| He et al. 2019             | Initial interest in being outdoors and learning moving to a stronger focus on contributing to science.                                                 | Environment                |
| Jakositz et al. 2020       | Health concerns, not motivated by incentives.                                                                                                          | Tap water                  |
| Jennett et al. 2016        | Curiosity, interest in science and desire to contribute to research.                                                                                   | Cyberscience               |
| Lakomý et al. 2020         | Younger people and men are more motivated by extrinsic incentives, while older people and women are more motivated by intrinsic incentives.            | Life sciences              |
| Land-Zandstra et al. 2016  | Interest in science and scientific topics, health and environment.                                                                                     | Aerosols                   |
| Larson et al. 2020         | As participation continued, science and conservation-related motivations became even more important                                                    | Environmental conservation |
| Lehman et al. 2020         | Social connectedness, personal learning, making a difference, and health benefits                                                                      | Health                     |
| Levontin et al. 2022       | Helping with research, benevolence, and self-direction. The least important motivators were self-enhancement (e.g. power, achievement, and conformity) | Diverse projects/topics    |
| Lorenzo et al. 2017        | Altruism and solidarity                                                                                                                                | Microbiomics               |
| Lotfian et al. 2018        | Contributing to scientific research                                                                                                                    | Biodiversity               |
| Lotfian et al. 2020        | Contributing to scientific research                                                                                                                    | Diverse projects/topics    |

| Reference                | Motivations to participate in CSP                                                                                                                                                                     | Topic/focus of CSP         |
|--------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|
| Maund et al. 2020        | Values and understanding, rather than career development or social interaction                                                                                                                        | Environmental conservation |
| Kaplan Mintz et al. 2022 | Learning through social interactions was the main driver as well as contribution to nature conservation.                                                                                              | Ecology                    |
| Moczek et al. 2021       | Altruistic motivations more important than egoistic motivations.                                                                                                                                      | Life sciences              |
| Nov et al. 2011          | Collective and intrinsic motives.                                                                                                                                                                     | Technology                 |
| Nov et al. 2014          | Collective motives, norm-oriented motives, reputation, and intrinsic motives.                                                                                                                         | Diverse projects/topics    |
| Palacin et al. 2020      | Openness-to-change values like self-direction are important for initial participation in digital CSP. A diverse range of values, except for power, play a role in sustaining participation over time. | Radioactivity and water    |
| Dunkley, 2018            | Affective connections with local environments.                                                                                                                                                        | Woodland and rivers        |
| Raddick et al. 2013      | Desire to contribute to scientific research.                                                                                                                                                          | Planets/Universe           |
| Rambonnet et al. 2024    | Desire to take action against plastic pollution and help the environment, rather than an interest in scientific research.                                                                             | Diverse projects/topics    |
| Reed et al. 2013         | Social engagement, website interaction, and helping.                                                                                                                                                  | Diverse projects/topics    |
| Rotman et al. 2012       | Motivation is complex and changes dynamically over time, influenced by personal interests and external factors like attribution and acknowledgment.                                                   | Diverse projects/topics    |
| Rotman et al. 2014       | Initial participation is driven by self-directed motivations, while long-term participation involves both self-directed and collaborative motivations                                                 | Diverse projects/topics    |
| Sandhaus et al. 2018     | Internal motivation.                                                                                                                                                                                  | Gardens                    |
| Tiago et al. 2017        | Motivational factors influence the frequency of participation in CS activities.                                                                                                                       | Diverse projects/topics    |

| Reference          | Motivations to participate in CSP                                                                                                                                                       | Topic/focus of CSP |
|--------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|
| V. Curtis, 2015    | Contributing to scientific research and an interest in science.                                                                                                                         | On-line game       |
| Weeser et al. 2021 | Altruistic and collectivistic motivations for participation.                                                                                                                            | Water level        |
| West et al. 2021   | Most citizen scientists primarily motivated by values-based reasons, such as concern for the environment and others had a mix of egoistic (self-oriented) and values-based motivations. | Environment        |

The studies which have used theories of basic human values, the Volunteer Functions Inventory, and Self-determination theory have identified a range of motivating factors for participation in CSP, including the desire to contribute to scientific research, gain knowledge about the subject matter, support environmental protection, contribute to societal well-being, enjoy the activities, form new social connections, meet people with similar interests, and gain recognition for their contributions (Table 6.1). Among these, the motivation to contribute to scientific research has often been cited as one of the most significant drivers across different CS projects irrespective of the CS focus or topic (Lotfian et al., 2020). Thus, contribution to science becomes increasingly important as participation progresses (Larson et al., 2020). Nov et al (2014) confirmed that motivational factors, including collective motives and reputation, influence participation levels. However, no studies specifically addressing motivations in the context of radon research were identified.

### 6.3.2 Level of engagement and participation in Citizen Science

Participation is generally characterized by two main aspects: quality and degree (Shirk et al., 2012). According to (ibid:4), quality refers to “the extent to which a project’s goals and activities align with, respond to, and are relevant to the needs and interests of public participants” while degree pertains to the extent of participation in the research process, the duration of involvement (Ballard et al., 2008) or the number of participants (Wilmsen and Krishnaswamy, 2008). This paper focuses on the degree of participation, or level of engagement. Citizens can be engaged in CS projects in a number of ways (Bonney et al., 2009; Haklay, 2013). According to (Bonney et al., 2009:11), in CSP citizens can engage in “*choosing or defining questions for study, gathering information and resources, developing hypothesis about possible answers to questions, designing data collection methodologies, collecting data, analysing data, interpreting data and drawing conclusions, disseminating conclusions, and discussing results and asking new questions*”. The two main classifications of CS engagement are provided by Haklay (2013) a) Crowdsourcing, Distributed intelligence, Participatory research and Extreme citizen science- and b) contributory, collaborative and co-created projects.

Evidence shows that engagement levels vary, with most projects involving low levels of citizen participation, primarily in data collection and interpretation (Bautista-Puig et al., 2024). However, some projects demonstrate high levels of scientific engagement, developing specialized vocabularies and contributing to research outcomes (Barr et al., 2018). The factors influencing level of engagement include participants' existing science engagement levels, motivations, and specialization (Martin, 2017; Randler, 2022). In the

field of radon research, most CSP rely on the simplest form of participation—crowdsourcing—and manage to engage citizens only for measuring concentration of radon in dwellings following predefined protocols (Table 6.2). Andresz et al. (2023) attribute low participation and engagement in their radon-related CSP to factors such as declining public interest when radon levels were not exceeded, the topic's complexity, and cognitive/emotional responses to radon among others. Martell et al. (2023) found that motivations for participating in radon-related CSP varied, with most driven by information-seeking. Some participants were interested in radon levels in their homes, while others focused on its technical aspects or mitigation of their homes. Maintaining long-term motivation and stronger engagement beyond concerns for their own dwellings proved challenging (Martell et al., 2023). However, the factors that motivate varying levels of engagement in CS projects related to radon have yet to be systematically explored. Since radon is complex scientific and social problem involving environment, health, and technology (Hevey et al., 2023) we expect that *Intrinsic motivation leads to higher levels of engagement among citizen scientists*.

Table 6.2 Aim of citizen science projects in the field of radon and their level of engagement

| Reference                                                                                                            | Aim of the CS initiative                                                                       | Level of engagement                                                                  |
|----------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| Andresz et al. (2023)                                                                                                | Improve the radon diagnostics tools                                                            | Collect basic data according to a predefined protocol                                |
| Downs et al. 2010<br>Downs et al. 2009                                                                               | Testing and reporting of radon levels to vulnerable groups                                     | Refining research questions, collecting data, drawing conclusions & drafting reports |
| Martell et al. 2023                                                                                                  | Rising number of tests and mitigated homes                                                     | Refining research questions, collecting data, drawing conclusions & drafting reports |
| Oberle et al. 2019<br>Stanley et al., 2017, 2019, 2021<br><a href="http://www.evictradon.org">www.evictradon.org</a> | Radon testing and raise awareness                                                              | Collect basic data according to a predefined protocol                                |
| Pugliese et al., 2019<br>D'Avino et al., 2020                                                                        | Educate students on radioactivity and raise awareness                                          | Contribute data & help with basic interpretation                                     |
| Yazzie et al. 2020                                                                                                   | Assess the impact of housing features and environmental factors on radon concentration levels. | Collect basic data according to a predefined protocol                                |

|                                                                                                                                                                    |                                                                       |                                                       |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------|-------------------------------------------------------|
| Tsapalov et al. 2020<br>Tsapalov et al., 2018<br><a href="https://nbri.net.technion.ac.il/en/radon-project/">https://nbri.net.technion.ac.il/en/radon-project/</a> | Educate students on radioactivity, raise awareness and radon mapping  | Collect basic data according to a predefined protocol |
| Environmental Protection Agency (EPA) Ireland <sup>21</sup>                                                                                                        | Re-test and encourage mitigation                                      | Contribute data & help with basic interpretation      |
| Tennessee Radon Program <sup>22</sup>                                                                                                                              | Radon mapping                                                         | Collect basic data according to a predefined protocol |
| Stanifer et al., 2022                                                                                                                                              | Collect and interpret radon measurements;<br>Increase radon awareness | Contribute data & help with basic interpretation      |

## 6.4 Method

### 6.4.1 Case study

The RadoNorm Citizen Science Incubator, in the framework of the European RadoNorm H2020 project, featured seven initiatives addressing radon testing and mitigation of buildings across Europe. Recognized as the winner of the European Commission Citizen Science Ars Electronica Prize – honorary mention in 2024<sup>23</sup>, the Incubator exemplifies innovative CS practices in the radon risk field. The initiatives, conducted in a period between 2023 and 2024, provided participants with varying levels of engagement, ranging from crowdsourcing to extreme CS.

1. RadoNorm-Aerosol (Hungary): Ten senior high school students from two high schools designed, assembled, tested, and validated a toolkit for measuring indoor air quality components, including radon and CO<sub>2</sub>. Each of them could actively participate in refining the toolkit, interpreting results, and creating a dedicated internet page. Additionally, some students presented their findings at a scientific conference.

2. OCRA (Italy): In Abbadia San Salvatore, Siena, one of Italy's most radon-affected areas, citizens contributed by measuring radon levels, analysing data, and creating an interactive radon map. The project targeted households, schoolrooms, and workplaces, involving 173 citizens and 700 students from four

<sup>21</sup> <https://www.epa.ie/take-action/in-the-community/citizen-science/clean-air-projects/#> (accessed on 11.02.2025)

<sup>22</sup> <https://www.tn.gov/environment/sustainability/programs/radon.html> (accessed on 11.02.2025)

<sup>23</sup> <https://calls.ars.electronica.art/2024/prix/winners/10721/> (accessed on 6<sup>th</sup> of January, 2025)



schools. Participants could contribute to data collection, interpretation, shared results with the public and scientific community, and helped refine communication strategies.

3. AHS RadonHunt (Poland): Ten high school students collected and analysed soil, water, and air samples to map radon exposure risks across various locations. Through field trips and laboratory experiments, each of them could contribute to different stages of research: from data collection, analysis and interpretation. Some participants documented their activities through social media, developed educational videos, and presented their findings at scientific events.

4. RadAR CS (Portugal): Sixty high school students conducted a large-scale radon measurement campaign in dwellings and contributed to a design of a local communication strategy to raise awareness of radon risks. While much of their work focused on crowdsourcing through standardized data collection, their contribution to the communication strategy enabled participants to get engaged also in analysis, design, interpretation and dissemination.

5. RadonGPS (Slovakia): Forty-seven citizens, including fourteen technical construction students, measured radon levels and designed tailored mitigation solutions for buildings with high radon concentrations. Participants could actively contribute to data collection, analysis and problem-solving. Their scientific efforts culminated in recognition with a local university prize, highlighting their substantial involvement in participatory research, which blended technical application and research interpretation.

6. RadoNorm-SLO (Slovenia): In Slovenia's Bela Krajina region, 90 adult citizens participated in research focused on the effectiveness of radon mitigation techniques. Citizens had the option to engage in different levels: measuring indoor radon concentrations, diagnosing radon issues in buildings, assisting or conducting remediation, such as installing ventilation systems in buildings with elevated radon levels.

7. RadoHOW (Spain): Twenty-five citizens across five Spanish provinces measured radon levels in their homes and workplaces. This initiative focused on crowdsourcing, as participants collected data following a predefined protocol to assess differences in radon exposure based on geographical, geological, and structural factors. However, participants also had the opportunity to engage in interpreting the analysed data, as this was the first study to comprehensively measure accumulated radon exposure across both workplace and home environments.

These seven initiatives provided a unique opportunity for citizens to choose their level of engagement, with some participants deeply engaged in multiple stages of the research process and some merely in crowdsourcing activities.

#### 6.4.2 Data collection, measurements, and analysis

A mixed-method approach of quantitative method (on-line survey) and qualitative methods (group discussion and a content analysis of project reports) were utilized. The RadoNorm Ethical Committee provided guidance and oversight throughout the study.

**Quantitative method:** The data for the survey were collected through a Computer-Assisted Web Interviewing to the citizen scientists participating in the seven CS initiatives. The link was distributed to all participants after the last activities of CSP, between February and May, 2024, by the independent marketing company MEDIANA, a member of ESOMAR, headquartered in Slovenia. Some participants were unable to complete the online survey due to technological limitations (e.g., "*Most participants were older adults or had limited online computer skills*"), while some students were unable to participate due to school transitions (e.g., "*They graduated from secondary school and moved on to university*"). The final sample size was (N=231) and consisted of only those who completed the survey. The response rate was 32.04% (Table 6.3).

The questionnaire began by asking respondents to specify which initiative they had participated in, followed by an open-ended question to describe their personal contribution to the initiative in their own words. Next, the questionnaire asked participants to rate their **level of engagement**. This was followed by a series of questions about their **previous experiences** with citizen science projects. The next section of the questionnaire focused on **personal values and motivations**, where participants were asked to indicate their responses to concepts such as **Social Cooperation, Self-Direction, Stimulation, Routine, Hedonism, Achievement, Power, and Resources**, as well as **Dominance, Face, Social Expansion, Security, Conformity, Benevolence, and Universalism**. Afterward, the survey addressed specific factors related to the **research context**, including **helping with research, teaching, and radon risk awareness**. Questions were included to assess **risk perception, radon knowledge, and radon protection behaviour**. Respondents were also asked about their **intention to protect from radon** and various aspects of risk, such as **severity, susceptibility, response efficacy, and self-efficacy**. Further sections focused on the **practical dimensions** of participation, including **perceived costs and perceived ease** of engaging in the activities. Social influences were explored through questions on **subjective norms and descriptive norms**, followed by an inquiry into the **willingness to engage** in future activities. Finally, the questionnaire concluded with a set of **socio-demographic items**, designed to provide context on the respondents' background and characteristics. Most survey items were structured as questions or statements, with responses mostly collected using a 5-point Likert scale ranging from "strongly disagree" to "strongly agree." However, some response categories were tailored to specific items. Additionally, an "I don't know" answering option was available for all questions or statements. I don't know responses were excluded from the quantitative analysis. To understand the motivations of "don't know" and non-respondents, project reports together with a group discussion with the coordinators of the CSP allowed us to complement the data.

Table 6.3 Survey sample and response rate

| CS project                | No. of responses | % of total | No. of participants in the initiative | Response rate |
|---------------------------|------------------|------------|---------------------------------------|---------------|
| RadoNorm-Aerosol, Hungary | 6                | 2.60       | 10                                    | 60.00%        |
| OCRA, Italy               | 25               | 10.80      | 173*                                  | 14.45%        |
| AHS RadonHunt, Poland     | 12               | 5.20       | 14                                    | 85.71%        |
| RadAR, Portugal           | 81               | 35.10      | 360                                   | 22.50%        |
| RadonGPS, Slovakia        | 31               | 13.40      | 49                                    | 63.27%        |
| RadoNorm-SLO, Slovenia    | 55               | 23.80      | 90                                    | 61.11%        |
| RadoHow, Spain            | 21               | 9.10       | 25                                    | 84.00%        |
| Total                     | 231              | 100.00     | 721                                   | 32.04%        |

\* Only adult participants were included in the survey.

For this study, only a specific subset of concepts, derived from the theoretical framework, were analysed.

The CSMS includes 37 items across 15 categories. The items were used for reflective and formative scales. Reflective scales assume that the construct causes the observed relationships between items, while formative scales assume that the items define the construct (Perko & Hevey, 2024). Each latent construct was represented by two to three items. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was employed to assess the suitability of the motivation scales for factor analysis of: '**stimulation**', '**power**', '**social expansion**', '**benevolence**', '**universalism-social**', and '**help with research**' (KMO>0.60). Cronbach's alpha ranged from 0.72 to 0.88, indicating good reliability. The correlation coefficient between items along with the Spearman-Brown coefficient are presented Table 6.11 in Appendix.

**Intrinsic motivation** was assessed with nine items related to: Performance of activity for its own sake, Driven by interest, enjoyment and or satisfaction, Autonomy (self-directed actions) and Persistence (in the absence of rewards/recognition)) measuring "hedonism", "security", "stimulation", "social expansion", "benevolence", "universalism, social", "help with research", "self-direction", and "teaching" (Ryan and Deci, 2020). Principal axis factoring revealed a single factor accounting for 56.42% of the total variance (N=205). The KMO value of 0.85 indicates a very good level of sampling adequacy for factor analysis (Cronbach's alpha = 0.9). **Extrinsic motivation** was assessed using four items related to: Driven by external rewards, Pressure to achieve outcomes, Avoidance of punishment or consequences, Compliance and control measuring "achievement", "face", "conformity" and "power" 2020). Principal axis factoring revealed a single

factor accounting for 57.13% of the total variance (N=215). (KMO =0.74; Cronbach's alpha=0.73). Factor loadings of the items in Table 6.12 in Appendix.

The level of engagement (Shirk et al., 2012), was assessed by the question: “Could you indicate your involvement in the CS project on the following scale?” with answering categories as: “I am not really involved”, “I am receiving information about the CS project for instance at workshops, information meetings”, “I am collecting data for the CS project for instance radon measurements”, “I am contributing to several stages of the research, like collecting and interpreting data and drawing conclusions”, “I am deeply engaged in all the phases of the research project from the first information meeting (defining the problem) to the end (publishing the results)”, and “I don't know”. In addition, an open-ended question where respondents were asked to describe their personal contribution to the initiative in their own words. The open questions have been analysed in a qualitative way.

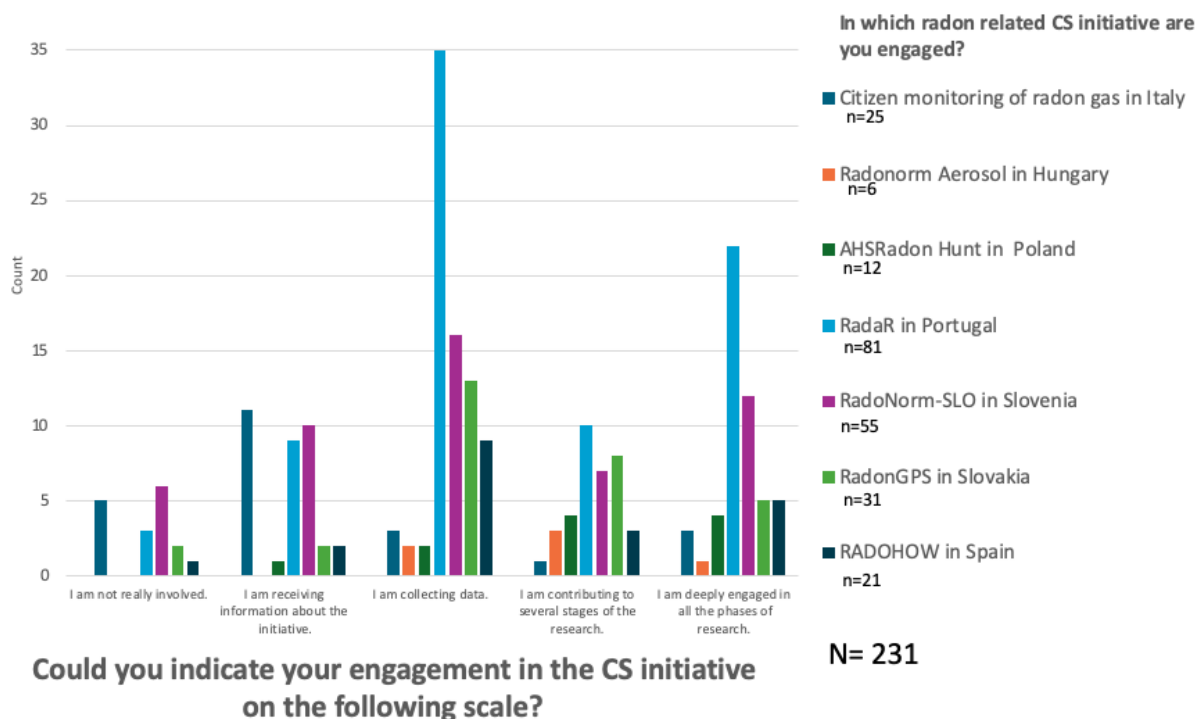
**Qualitative methods:** A group discussion involving ten participants - coordinators of CSP was held *in person* on June 11, 2024. The discussion followed the protocol and focused on the following themes: experiences and challenges in engaging and motivating participants in CSP, the implementation of CSP, their societal impact, and the requirements for ensuring long-term sustainability. The 120-minute session was facilitated according to a dedicated protocol to ensure that each CSP had sufficient time to share their thoughts and insights on each topic. Inductive coding in NVivo was utilized to identify themes and codes. In addition, an analysis of seven internal final project reports was conducted to analyse the motivation types outlined by Nov et al. (2011): collective motivation (The citizen scientist sees the project aims as important), norm-related motivation (the participant hopes for positive responses from friends, family, or work-mates), motivation based on reward (extrinsic) (participation brings real benefits, such as building a reputation or making new friends), collective identification (the participant identifies with the group, its norms, and its values) and hedonistic/intrinsic motivation (participation gives joy or pleasure).

## 6.5 Results

### 6.5.1 Level of engagement in the CS initiatives

Figure 1 shows that each CSP provided opportunities for participants to engage at various levels. In the Italian CSP, most participants received information through workshops and information meetings (e.g. “*I attended a lecture and measured the radon level at home*”). In Portugal, Slovenia, Slovakia and Spain a larger proportion of participants engaged in data collection activities. (e.g. “*I carried out radon measurements at my workplace and at home using both continuous and passive detectors.*”). Those initiatives also successfully engaged participants at higher levels throughout all phases of the research project—from the initial information meetings (defining the problem) to the final stage (publishing results). (e.g., “*I was helping to understand radon levels in the area where I live and sharing this information with the population to prevent diseases caused by this toxic gas.*”). The high school CS initiatives in Hungary and Poland successfully engaged participants in the highest level of participation, with most students contributing to multiple stages of the research, such as data collection, interpretation, and drawing conclusions. Many were deeply involved in all phases of the research process. (e.g. “*I was the initiator and coordinator of the initiative, handling all its stages, administration, measurements and analysis.*”)

Figure 6.1 Levels of engagement in the evaluated CSP



Results show that the RadoNorm CS incubator represents a meaningful advancement in engaging a traditionally underrepresented group in CS. The projects engaged participants across a wide range of age groups, allowing individuals of all ages to contribute. Approximately 53% of participants were women, demonstrating a departure from the typical male-dominated landscape of CS projects. This is particularly significant considering Strasser et al. (2023), who note that, outside of nature-sensing CS projects, men participants generally dominate.

### 6.5.2 Participation motivators

The qualitative analysis reveals that participants were primarily motivated by collective and extrinsic factors, followed by norm-related motivations, intrinsic motivations, and, lastly, collective identification. For instance, a collective motivation, such as recognizing radon as a public health issue, and extrinsic incentives, like receiving a free radon test, emerged as key drivers for adult participants. Meanwhile, for students, rewards in the form of enhanced CVs or grades served as primary motivators. Notably, these motivational factors evolved over time. Initially, participants were largely driven by collective motivations. However, as the CSP progressed, norm-related motivations and enthusiasm for rewards gained prominence.

Table 6.4 presents selected statements illustrating these motivational factors across various CSP.

Table 6.4 Selected expressions of motivation across CSP

| CSP                       | Selected statements related to motivation from qualitative analysis (type of motivation)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|---------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| RadoNorm-Aerosol, Hungary | <i><sup>b</sup>“Students were motivated to join the initiative by both the previously involved students in similar citizen science project related to radon”; <sup>c</sup>“Teachers promised a reward with grades”.</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| OCRA, Italy               | <i><sup>a</sup>“.. living in a radon-prone area encouraged citizens to be interested in and take part in the project”; <sup>d</sup>“... the health risk information shared during the project presentation motivated them to engage”.</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| AHS RadonHunt, Poland     | <i><sup>b</sup>“Students needed to join one of the projects proposed by the school.” ; <sup>e</sup>“This project offered working with real equipment and participating in exciting trips. It was perceived as a great adventure.”; <sup>c</sup>“As high school students are aware of the highly competitive process of university applications, some perceive projects as a way to strengthen their academic portfolio.”; <sup>e</sup>“...this project offered a break in a routine, visiting interesting places, the ability to test ideas and hypotheses, joy of doing something new.”; <sup>c</sup>“The perspective of writing journal articles, networking with scientists, building a professional portfolio may help obtain funding in the future.”</i> |
| RadAR, Portugal           | <i><sup>d</sup>“The creation of a competition between schools for awards turned out to be an incentive, since these young scientists are highly competitive.”; <sup>a,b,e</sup> “ At the beginning, it was more because it is a serious health problem and towards the end participants received positive responses from significant others and enjoyed the activities.”</i>                                                                                                                                                                                                                                                                                                                                                                                  |
| RadonGPS, Slovakia        | <i><sup>a</sup>“...the gas that is everywhere around us, is harmful to health and can increase the risk of lung cancer.”; <sup>d</sup>“They were most surprised that they definitely have radon in their house;”; <sup>c</sup>“...they can provide measurements of the indoor radon activity concentration in their houses.”; <sup>d</sup>“that they will participate in a project funded by the EC”; <sup>c</sup>“.. the fact that they would meet more people and communicate with each other.”; <sup>c</sup>“...their teachers promised that their tailor-made radon remediation projects for a family house would be accepted as a final project at school.”</i>                                                                                          |
| RadoNorm-SLO, Slovenia    | <i><sup>c</sup>“...driven by the opportunity to measure radon concentrations in their homes free of charge.”; <sup>a</sup>“the project team hoped to directly involve citizens in the scientific process, thus fostering a more community-driven effort to address a public health problem.”</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| RadoHow, Spain            | <i><sup>a</sup>“...genuine concern about radon gas issues and the low visibility of this problem in society, especially as conveyed by those already affected”; <sup>c</sup>“ they gained</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |

|  |                                                                                                                                                                       |
|--|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  | <i>tangible benefits such as continuous measurements, in-depth analysis and knowledge for ongoing monitoring.”; <sup>e</sup>“They found participation enjoyable.”</i> |
|--|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|

<sup>a</sup> Collective, <sup>b</sup> Norm-related, <sup>c</sup> Extrinsic, <sup>d</sup> Collective identification, <sup>e</sup> Hedonistic/intrinsic motivation

The results indicate that participation significantly declines over time when participants are motivated by extrinsic factors. For example, the coordinators of the CSP observed a notable drop in participation of the adult citizen scientists after the radon testing phase concluded, especially when participants learned that radon concentrations in their homes were low.

The survey results in Table 6.5 reveal that the top five motivators for participation were **security/safety, benevolence, self-direction, social universalism, and contributing to research**. Specifically, participants were primarily motivated by: concerns related to security/safety (i.e., the safety of oneself and others); benevolence (i.e., the desire to be helpful and well-meaning); self-direction (i.e., autonomy and independent thought); universalism (i.e., protecting society and the environment); and the opportunity to contribute to scientific research. Conversely, the lowest-ranked motivations included **power, achievement, and routine**, suggesting that gaining authority, financial benefits, or fulfilling personal ambitions were not significant factors for participation.

These findings imply that the key motivations for participation centered around protecting oneself and society from radon exposure, as well as a general willingness to contribute to research and the common good. By contrast, motivations related to personal gain or familiar routines were less important.

Motivations varied across the CSP, with notable differences observed in the importance placed on specific motivational categories. For instance, in Italy (OCRA), the top five motivations were security, benevolence, help with research, universalism (social), and self-direction. Participants from Hungary (RadoNorm-Aerosol) ranked security and benevolence highest, followed by help with research, self-direction, social expansion, and teaching. For Poland (AHS RadonHunt), students prioritized self-direction, help with research, teaching, benevolence, and stimulation. Similarly, participants of RadAR (Portugal) placed security, benevolence, universalism, self-direction, and help with research as their top motivations. In RadonGPS (Slovakia), conformity, benevolence, self-direction, security, and universalism were most important. In Slovenia, RadoNorm-SLO participants ranked security/safety, self-direction, benevolence, help with research, and stimulation as their key motivators. In Spain (RadoHOW), the leading motivations were self-direction, benevolence, universalism, help with research, and security. Nonetheless, the lowest ranked motivations across initiatives were power, routine and achievement with face replacing achievement in some countries.

Table 6.5 Mean scores of motivational categories for engagement in the CS projects

| CS Initiative |      | Self-direction | Stimulation | Routine | Hedonism | Achievement | Power Resources | Power Dominance | Power | Face | Social Expansion | Security    | Conform | Benevolence. | Universal   | Research    | Teaching    |
|---------------|------|----------------|-------------|---------|----------|-------------|-----------------|-----------------|-------|------|------------------|-------------|---------|--------------|-------------|-------------|-------------|
| OCRA          | Mean | <b>3.98</b>    | 3.69        | 2.09    | 2.99     | 1.48        | 1.79            | 2.15            | 1.76  | 2.5  | 3.18             | <b>4.37</b> | 3.15    | <b>4.22</b>  | <b>4.13</b> | <b>4.17</b> | 3.85        |
|               | N    | 25             | 25          | 23      | 25       | 24          | 24              | 24              | 24    | 25   | 24               | 23          | 24      | 24           | 24          | 24          | 24          |
|               | SD   | 0.55           | 0.75        | 0.75    | 0.64     | 0.63        | 0.85            | 0.71            | 0.77  | 0.85 | 0.64             | 0.63        | 0.77    | 0.41         | 0.52        | 0.49        | 0.7         |
| Aerosol       | Mean | <b>4.58</b>    | 4.17        | 2.08    | 3.78     | 2.67        | 1.92            | 3.08            | 2.17  | 3.5  | <b>4.44</b>      | <b>4.67</b> | 4.4     | <b>4.67</b>  | 4.28        | <b>4.61</b> | <b>4.42</b> |
|               | N    | 6              | 6           | 6       | 6        | 6           | 6               | 6               | 6     | 6    | 6                | 6           | 5       | 6            | 6           | 6           | 6           |
|               | SD   | 0.49           | 0.69        | 1.32    | 0.62     | 0.61        | 0.66            | 1.07            | 0.72  | 0.32 | 0.5              | 0.52        | 0.89    | 0.52         | 0.57        | 0.49        | 0.8         |
| AHS           | Mean | <b>4.71</b>    | <b>4.33</b> | 2.71    | 3.72     | 3           | 1.92            | 2.38            | 2.08  | 3.13 | 4.11             | 4.04        | 3.38    | <b>4.39</b>  | 4.25        | <b>4.47</b> | <b>4.42</b> |
|               | N    | 12             | 12          | 12      | 12       | 12          | 12              | 12              | 12    | 12   | 12               | 12          | 12      | 12           | 12          | 12          | 12          |
|               | SD   | 0.4            | 0.51        | 0.75    | 0.72     | 0.64        | 0.95            | 1.09            | 0.83  | 0.74 | 0.69             | 1.03        | 0.98    | 0.49         | 0.7         | 0.52        | 0.67        |
| RadAR         | Mean | <b>4.32</b>    | 4.08        | 2.19    | 3.37     | 2.36        | 1.84            | 2.56            | 1.94  | 2.76 | 3.88             | <b>4.5</b>  | 3.58    | <b>4.37</b>  | <b>4.35</b> | <b>4.29</b> | 4.14        |
|               | N    | 81             | 81          | 80      | 80       | 81          | 81              | 81              | 81    | 81   | 80               | 79          | 80      | 80           | 80          | 80          | 80          |
|               | SD   | 0.48           | 0.61        | 0.79    | 0.59     | 0.8         | 0.92            | 1.11            | 0.97  | 0.95 | 0.66             | 0.5         | 0.91    | 0.55         | 0.56        | 0.54        | 0.63        |

| CS Initiative   |      | Self-direction | Stimulation | Routine | Hedonism | Achievement | Power Resources | Power Dominance | Power | Face | Social Expansion | Security    | Conform     | Benevolence. | Universal   | Research    | Teaching |
|-----------------|------|----------------|-------------|---------|----------|-------------|-----------------|-----------------|-------|------|------------------|-------------|-------------|--------------|-------------|-------------|----------|
| RadoNorm<br>SLO | Mean | <b>4.35</b>    | <b>4.03</b> | 2.55    | 3.35     | 2.08        | 1.8             | 2.18            | 1.79  | 2.76 | 3.86             | <b>4.44</b> | 3.28        | <b>4.22</b>  | 4.02        | <b>4.04</b> | 3.92     |
|                 | N    | 55             | 55          | 55      | 55       | 55          | 55              | 55              | 55    | 54   | 55               | 54          | 54          | 54           | 55          | 55          | 55       |
|                 | SD   | 0.53           | 0.7         | 0.86    | 0.73     | 0.73        | 0.9             | 0.8             | 0.84  | 0.97 | 0.64             | 0.7         | 0.95        | 0.53         | 0.58        | 0.65        | 0.67     |
| RadonGPS        | Mean | <b>4.15</b>    | 3.95        | 2.19    | 3        | 2.93        | 2.38            | 2.87            | 2.46  | 3.07 | 3.89             | <b>4.11</b> | <b>4.24</b> | <b>4.23</b>  | <b>4.05</b> | 3.89        | 4.02     |
|                 | N    | 31             | 31          | 31      | 31       | 29          | 29              | 30              | 29    | 29   | 31               | 31          | 31          | 31           | 31          | 31          | 29       |
|                 | SD   | 0.64           | 0.7         | 0.97    | 0.83     | 0.97        | 0.9             | 0.76            | 0.92  | 0.94 | 0.79             | 0.77        | 0.89        | 0.62         | 0.72        | 0.8         | 0.78     |
| RadoHOW         | Mean | <b>4.55</b>    | 4.08        | 2.76    | 3.52     | 2.4         | 2.02            | 2.3             | 2.06  | 2.64 | 3.76             | <b>4.36</b> | 3.83        | <b>4.48</b>  | <b>4.44</b> | <b>4.41</b> | 4.24     |
|                 | N    | 21             | 21          | 21      | 21       | 20          | 21              | 20              | 21    | 21   | 21               | 21          | 21          | 21           | 21          | 21          | 21       |
|                 | SD   | 0.59           | 0.83        | 0.77    | 0.72     | 0.88        | 0               | 0.8             | 0.95  | 0.87 | 0.76             | 0.62        | 0.94        | 0.57         | 0.52        | 0.61        | 0.68     |

### 6.5.3 Motivational factors predicting level of engagement

We employed stepwise regression to identify the motivation categories and types that best predict citizen scientists' engagement levels in the CSP and their willingness to participate in similar future CSP. The results (Mean engagement level=3.29, SD=1.19, N=209) in Table 6.6, suggest that "hedonism" and "social expansion" are positive predictors of the level of engagement. This indicates that participants motivated by enjoyment and social interaction are more likely to be involved in several stages of CS research. Conversely, "security" is a negative predictor, suggesting that citizens with a higher concern for security are less likely to engage in more stages of the project.

Table 6.6 Stepwise regression predicting level of engagement and CSMS.

| Model | Motivation Category | B     | Std. Error | Beta  | t     | p     | 95,0% Confidence Interval for B |             |
|-------|---------------------|-------|------------|-------|-------|-------|---------------------------------|-------------|
|       |                     |       |            |       |       |       | Lower Bound                     | Upper Bound |
| 1     | (Constant)          | 1.36  | 0.37       |       | 3.66  | <.001 | 0.63                            | 2.09        |
|       | Hedonism            | 0.58  | 0.11       | 0.35  | 5.31  | <.001 | 0.37                            | 0.80        |
| 2     | (Constant)          | 0.38  | 0.47       |       | 0.81  | 0.42  | -0.54                           | 1.29        |
|       | Hedonism            | 0.42  | 0.12       | 0.25  | 3.56  | <.001 | 0.19                            | 0.65        |
|       | Social expansion    | 0.40  | 0.12       | 0.24  | 3.37  | <.001 | 0.17                            | 0.63        |
| 3     | (Constant)          | 1.11  | 0.59       |       | 1.89  | 0.06  | -0.05                           | 2.27        |
|       | Hedonism            | 0.44  | 0.12       | 0.26  | 3.74  | <.001 | 0.21                            | 0.67        |
|       | Social expansion    | 0.48  | 0.12       | 0.28  | 3.85  | <.001 | 0.23                            | 0.72        |
|       | Security            | -0.25 | 0.12       | -0.14 | -2.03 | 0.04  | -0.49                           | -0.01       |

$R^2 = 0.182$ ; Adj.  $R^2 = 0.17$ ; DW= 2.05;  $F(3, 205) = 15.22$ ,  $p < .001$

*Dependent variable: Level of engagement*

Focusing on participants aged 15–19, the analysis reveals outcomes consistent with those observed for all participants, where intrinsic motivation, rather than extrinsic motivation, correlates significantly with the level of engagement, albeit with a higher coefficient.

Table 6.7 Correlations between level of engagement, motivational types, and other characteristics

|                         | Spearman's rho | Level of engagement | Extrinsic motivation | Intrinsic motivation | Gender        | Highest diploma |
|-------------------------|----------------|---------------------|----------------------|----------------------|---------------|-----------------|
| Level of engagement     |                |                     |                      |                      |               |                 |
| Correlation Coefficient | --             |                     |                      |                      |               |                 |
| Sig. (2-tailed)         | .              |                     |                      |                      |               |                 |
| N                       | 223            |                     |                      |                      |               |                 |
| Extrinsic motivation    |                |                     |                      |                      |               |                 |
| Correlation Coefficient | <b>.190**</b>  | --                  |                      |                      |               |                 |
| Sig. (2-tailed)         | 0.006          | .                   |                      |                      |               |                 |
| N                       | 207            | 215                 |                      |                      |               |                 |
| Intrinsic motivation    |                |                     |                      |                      |               |                 |
| Correlation Coefficient | <b>.314**</b>  | 0.06                | --                   |                      |               |                 |
| Sig. (2-tailed)         | <.001          | 0.401               | .                    |                      |               |                 |
| N                       | 198            | 198                 | 205                  |                      |               |                 |
| Gender <sup>a</sup>     |                |                     |                      |                      |               |                 |
| Correlation Coefficient | -0.085         | <b>-.193**</b>      | 0.075                | --                   |               |                 |
| Sig. (2-tailed)         | 0.214          | 0.005               | 0.293                | .                    |               |                 |
| N                       | 217            | 210                 | 201                  | 225                  |               |                 |
| Highest diploma         |                |                     |                      |                      |               |                 |
| Correlation Coefficient | -0.004         | -0.059              | 0.028                | 0.065                | --            |                 |
| Sig. (2-tailed)         | 0.953          | 0.4                 | 0.696                | 0.346                | .             |                 |
| N                       | 209            | 203                 | 194                  | 215                  | 216           |                 |
| Age                     |                |                     |                      |                      |               |                 |
| Correlation Coefficient | <b>-.248**</b> | <b>-.330**</b>      | -0.128               | <b>.151*</b>         | <b>.411**</b> |                 |
| Sig. (2-tailed)         | <.001          | <.001               | 0.067                | 0.023                | .001          |                 |
| N                       | 223            | 215                 | 205                  | 225                  | 216           |                 |

The findings on level of engagement and potential factors from self-determination theory (SDT) (Table 6.7 and Table 6.8) with mean engagement level of 3.31 (SD=1.16, N=180), demonstrate that intrinsic motivation is a significant positive predictor of level of engagement. This indicates that higher intrinsic motivation is associated with higher levels of engagement in the RadoNorm CS incubator. Age shows a negative and significant correlation with both level of engagement and extrinsic motivation, suggesting that older individuals tend to exhibit lower levels of engagement and are less driven by external rewards.

Table 6.8 Stepwise regression predicting level of engagement and the SDT.

|       |                      |       |            |       |       |       | 95.0% Confidence Interval for B |             |
|-------|----------------------|-------|------------|-------|-------|-------|---------------------------------|-------------|
| Model | Motivation Category  | B     | Std. Error | Beta  | t     | p     | Lower Bound                     | Upper Bound |
| 1     | (Constant)           | 3.28  | 0.08       |       | 39.65 | <.001 | 3.12                            | 3.44        |
|       | Intrinsic motivation | 0.41  | 0.09       | 0.32  | 4.52  | <.001 | 0.23                            | 0.59        |
| 2     | (Constant)           | 3.84  | 0.25       |       | 15.68 | <.001 | 3.35                            | 4.32        |
|       | Intrinsic motivation | 0.39  | 0.09       | 0.31  | 4.34  | <.001 | 0.21                            | 0.57        |
|       | Age group            | -0.20 | 0.08       | -0.17 | -2.41 | 0.02  | -0.36                           | -0.04       |

$R^2 = 0.13$ ; Adj.  $R^2 = 0.12$ ; DW= 2.16; F (2, 177) = 13.41,  $p < .001$

*Dependent variable: Level of engagement*

The results on willingness to participate in similar future CSP and SDT (Mean=3.35, SD=1.16, N=173) in Table 6.9 show that intrinsic motivation is the strongest predictor of willingness to participate in future projects. This suggests that individuals with higher intrinsic motivation are more likely to engage in future CSP.

Table 6.9 Stepwise regression predicting willingness to engage in similar future CSP and SDT.

|       |                      |      |            |      |       |       | 95.0% Confidence Interval for B |             |
|-------|----------------------|------|------------|------|-------|-------|---------------------------------|-------------|
| Model | Motivation Category  | B    | Std. Error | Beta | t     | p     | Lower Bound                     | Upper Bound |
| 1     | (Constant)           | 3.31 | 0.08       |      | 39.84 | <.001 | 3.14                            | 3.47        |
|       | Intrinsic motivation | 0.45 | 0.09       | 0.36 | 5.09  | <.001 | 0.28                            | 0.63        |

$R^2 = 0.13$ ; Adj.  $R^2 = 0.13$ ; DW= 2.07; F (1, 171) = 25.95,  $p < .001$

*Dependent variable: Willingness to engage*

For willingness to participate based on the CSMS, the results (Mean=3.32, SD=1.20, N=201) in Table 6.10 indicate that "stimulation" and "help with research" are the most significant predictors. This suggests that individuals motivated by a desire for stimulation and a drive to contribute to research are more likely to participate in more stages of CS research in similar future projects.

Table 6.10 Stepwise regression predicting willingness to participate in similar future CS projects via the CSMS.

| Model | Motivation Category | 95.0% Confidence Interval for B |            |      |       |       |             |             |
|-------|---------------------|---------------------------------|------------|------|-------|-------|-------------|-------------|
|       |                     | B                               | Std. Error | Beta | t     | p     | Lower Bound | Upper Bound |
| 1     | (Constant)          | 0.56                            | 0.49       |      | 1.15  | 0.25  | -0.41       | 1.53        |
|       | Stimulation         | 0.68                            | 0.12       | 0.37 | 5.68  | <.001 | 0.44        | 0.91        |
| 2     | (Constant)          | -0.37                           | 0.59       |      | -0.63 | 0.53  | -1.52       | 0.79        |
|       | Stimulation         | 0.50                            | 0.13       | 0.28 | 3.81  | <.001 | 0.24        | 0.77        |
|       | Help with research  | 0.39                            | 0.14       | 0.20 | 2.80  | 0.01  | 0.11        | 0.66        |

$R^2 = 0.17$ ; Adj.  $R^2 = 0.16$ ; DW= 2; F (2, 198) = 20.57,  $p < .001$

*Dependent variable: Willingness to engage*

The qualitative study revealed that the sustained motivation of some participants, particularly students, is driven by extrinsic factors such as rewards and a sense of achievement. In addition, student participants tended to adhere closely to teachers and their initial and / or sustained motivation may have been due to such conformity. The following motivations were mentioned as effective by coordinators of the CSP: Achievement (e.g. "regardless of the topic, the notion that they are now creating content for a particular social media and their colleagues from the school see that there are the videos."); Active participation (e.g. "They were very active. Can we do this? Can we do that?"); Conforming to teachers (e.g. "Teacher, naturally, is for them someone that delivers education. So, in the end, actually, no one asks if they are interested or not because for them it might be part of the curriculum."); Empowerment (e.g. "It was really nice to see how happy people were because we actually solved some complete issues, which is almost never the case in a European project."; "So even though the project ended, they have the results and they understand what's happening and can act accordingly."); Interest to continue (e.g. "And then some of them who found quite high levels [of radon], they are now interested in continuing with monitoring with the research group."); Reward-based motivation (e.g. "We had this competition between the classes in our project. We thought it was a good way of keeping the students motivated to do the work."); Security (e.g. "Some of them were interested about the rate and activity concentration measurement."); Self-esteem (e.g. "They were excited when they saw that immediately on the particular social media we had hundreds of views in a day. They got over excited that now they are famous."). (Table 6.13 in Annex).

The group discussion highlighted additional challenges in motivation and level of engagement, including insufficient time to fully engage participants at all research stages, difficulties in recruiting volunteers, and

participants struggling with analysing complex radon data, all of which negatively impacted motivation and engagement.

## 6.6 Discussion

Results show that intrinsic motivation leads to high levels of engagement among citizen scientists. The research identified that the motivators for citizens to engage in CSP are concerns for safety and societal stability, help with research, benevolence, universalism, and self-direction. Conversely, power, achievement, and conformity were the least motivating factors. This results align closely with the findings of Levontin et al. (2022) in three different projects. Unlike Levontin et al. (2022), where security concerns influence only one project, our study found security as the top motivational factor. On the other hand, while power and achievement were among the least ranked motivations, consistent with the findings of (Levontin et al., 2022), routine emerged as the third lowest-ranked motivation in the current study, whereas conformity ranked as the fourth lowest. In contrast, Levontin et al. (2022) identified conformity as one of the least motivating factors.

Consistent with findings that most citizen scientists participate in CSP to contribute to science (Curtis, 2015; Land-Zandstra et al., 2021; Raddick et al., 2010), help with research emerged as one of the top five motivations for the entire dataset and across almost all the CS projects, with only one exception. In general, the current findings on the top five motivations are consistent with the outcomes of other studies especially on benevolence, universalism, help with research and self-direction (Berghen et al., 2024; Celino et al., 2021; Larson et al., 2020). The current findings are also in line with those from previous research utilizing the Volunteer Functions Inventory (VFI), such as Maund et al. (2020), where values and understanding were identified as the strongest motivators in conservation CSP. Values relate to a sense of environmental responsibility and support for scientific research, paralleling the themes of universalism, security, and the desire to help with research identified in this study. Understanding, in turn, refers to learning and knowledge acquisition, corresponding to self-direction.

Similarly, the least-ranked motivations align with previous research findings (Berghen et al., 2024; Celino et al., 2021; Larson et al., 2020). Achievement was one of the least motivating factors in this study, which aligns with Maund et al. (2020), who found that career advancement was not a significant motivator for participants in CSP. Given that power and achievement are primarily associated with external, reward-based incentives, it can be inferred that citizen scientists in the current study were predominantly driven by intrinsic motivations rather than extrinsic factors. Indeed, the stepwise regressions revealed intrinsic motivations as a key predictor of participants level of engagement. This aligns with (Nov et al., 2011) that intrinsic motivators are important in keeping citizen scientists engaged. Furthermore, the current results are similar to studies using a single question to elicit citizen scientists' motivations (Alender, 2016; Duerinckx et al., 2021; West et al., 2021), where contribution to science (help with research), appears as a key motivator whilst receiving rewards for participating, such as awards or certificates, garners less agreements (Alender, 2016; Duerinckx et al., 2021; Lotfian et al., 2020).

The level of engagement in Citizen Science initiatives varies depending on the structure of the project, with participants in school-based initiatives demonstrating higher engagement across multiple research phases, while those in community-based projects primarily engage in data collection and information-sharing activities. In projects with students, such as RadoNorm-Aerosol and AHS RadonHunt, teaching emerged as one of the five key motivational factors. Teaching was also ranked as the sixth highest motivator in the

RadonGPS project, which included both students and adult participants. This emphasizes the importance of education in projects targeting younger populations. In contrast, benevolence consistently ranked second in most CSP with adult participants and third in one project, suggesting that adults were more motivated by altruism or a desire to help and contribute positively to the community.

There was a negatively significant association between age and the level of engagement. Younger participants tended to be engaged in more stages of the research, while older participants were primarily engaged in data collection. Similarly, Hoedoafia et al. (2024) found that student citizen scientists were more engaged in multiple stages of the research process than their older counterparts.

Hedonism and self-expansion were key predictors of engagement level implying that enjoyment and opportunities for social interaction were crucial motivators. This finding contrasts with suggestions that participants in newer CSP were not motivated by social interaction (Maund et al., 2020). For future involvement in similar CSP, however, stimulation and the desire to contribute to research emerged as the main motivational predictors. This may suggest that the novelty of the CS incubator sparked initial excitement, which might have developed into a deeper appreciation for the importance of contributing to science.

Moreover, intrinsic motivation emerged as a significant predictor of both current and future engagement levels in similar CSP. This finding suggests that motivation stemming from internal factors, such as personal interest, satisfaction, and a sense of purpose, rather than external incentives or rewards, plays a crucial role in driving citizens to engage in CS initiatives and to be involved in more stages of the research process. Understanding and fostering intrinsic motivations may therefore be essential for sustaining long-term engagement and commitment in CS. Indeed, across multiple studies, citizen scientists have reported being motivated by personal interest, desire to contribute to science, and the opportunity to learn (Alender, 2016; Lotfian et al., 2018; Maund et al., 2020; Nov et al., 2011). Extrinsic rewards were generally found to be less important (Jakositz et al., 2020; Maund et al., 2020; Nov et al., 2011).

On motivation, the analysis of the group discussion with CSP coordinators suggested that student participants might have been extrinsically motivated via rewards, achievement, and conformity. This is in line with previous research that while older volunteers tend to be driven by intrinsic motives like helping the environment and contributing to scientific knowledge, younger participants are more likely to be extrinsically motivated by career development and external rewards (Alender, 2016; Lakomý et al., 2020; West et al., 2021).

The study had several limitations. The six-month duration of the CSP may have been too short for participants, especially older ones, to engage fully beyond data collection. Additionally, in some countries, fewer participants completed the survey compared to those initially involved, potentially biasing the results toward those who remained engaged. Lastly, as the CSP were conducted in specific European countries, the findings may not be fully generalizable to other types of CS projects or regions, as the project context likely influenced the outcomes.

## 6.7 Implications for Citizen Science Projects

The insights gathered from this study have several important implications for the design, management, and long-term success of CSP.

Considering that hedonism and social-expansion predicted current level of participation, while future level of engagement was predicted by stimulation and a desire to contribute to science, it is important to balance personal and social engagement with learning opportunities and scientific contribution. This balance is essential for attracting short-term participants who seek enjoyment while retaining long-term participants invested in the scientific value of their contributions.

Fostering intrinsic motivation is important for sustaining long-term engagement in different stages of CS research. Since intrinsic motivations, such as personal interest, curiosity, and a sense of contribution, were identified as more influential than external rewards, CSP should focus on creating an engaging and meaningful experience that aligns with participants' internal values. For instance, in designing CSP, practitioners, researchers, and project leaders should emphasize the scientific value and societal impact of the work, allowing participants to feel a deeper connection to the project's goals. Clear communication about how their contributions support scientific research and public good can enhance their sense of purpose. Intrinsically motivated participants are more likely to stay committed to CSP over the long-term suggesting that initiatives that successfully nurture these motivations may experience higher retention rates, leading to more consistent and meaningful contributions over time. Therefore, by prioritizing intrinsic motivation and minimizing over-reliance on external incentives, CS initiatives can enhance participant satisfaction, project sustainability, and overall research quality.

The finding that a six-month timeframe was insufficient to engage participants in all stages of the research process, points to the need for extending project timelines. Hence, longer project durations might be necessary to allow participants to meaningfully engage in all stages of the research, from planning and data collection to analysis and reporting. Extending the timeline will give participants adequate time to build the skills needed for more complex tasks, particularly in extreme CS.

Lastly, although, most CS approaches have often had a top-down approach where citizens primarily engage in data collection (Ferran-Ferrer, 2015; Martell et al., 2021), adopting a bottom-up co-creation approach can enhance participation, offer opportunities for novel ideas and fresh perspectives and has the potential to lead to more locally relevant research designs, improved risk communication, and enhanced sustainability of projects (Froeling et al., 2021; Gignac et al., 2022; Hargitai et al., 2022; Van den Driesche and Kerklaan, 2022).

## 6.8 Conclusions

The findings on motivation revealed that participants—particularly those with higher levels of engagement over a longer period—were primarily driven by intrinsic motivational factors. Altruistic and socially oriented motivations, such as security, benevolence, universalism, and contributing to research, alongside self-direction, emerged as key drivers of citizen scientists' engagement at various stages of the research process. Conversely, while extrinsic motivations related to power, personal achievement, and conformity were recognized as significant, they were considered less influential in determining the level of engagement.

Variations in motivational factors across countries emphasize the influence of cultural and contextual context on participant engagement. While security and benevolence were universally significant, other motivations such as self-direction, teaching, and stimulation varied in importance depending on the country and project setting.

These insights can guide the design of future CSP, enabling them to align more closely with the motivations of diverse participant groups and thereby enhance engagement and impact. The key findings demonstrate that fostering intrinsic motivations is essential for optimizing participation beyond data collection. While shorter project durations and skill gaps present challenges, the study highlights the importance of providing extensive training and longer timelines to facilitate deeper involvement, particularly in more technical aspects of radon research.

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## 6.10 Appendix

Table 6.11 Constructs, Items, and Factor loadings of items (CSMS)

| Motivational Category/<br>Construct | Items (codes)                                                                     | Factor loading<br>Principal axis correlation<br>between two items | Cronbach's Alpha or<br>Spearman-Brown statistics for two items<br>out of 231(%) |
|-------------------------------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------|---------------------------------------------------------------------------------|
| Self-direction                      | I want to learn.                                                                  | 0.56                                                              | 0.69                                                                            |
|                                     | I participate out of curiosity.                                                   | (excluded)                                                        | N = 229 (99.1%)                                                                 |
|                                     | It's an opportunity to explore new things.                                        | 0.56                                                              |                                                                                 |
| Stimulation                         | I want to do something new.                                                       | 0.76                                                              | 0.79                                                                            |
|                                     | I strive to challenge myself.                                                     | 0.85                                                              | N = 222 (96.1%)                                                                 |
|                                     | I want to know how to use scientific instruments (for instance, radon detectors). | 0.65                                                              | KMO = 0.69                                                                      |
| Routine                             | I'm a regular participant in citizen science projects.                            | 0.36                                                              | 0.47                                                                            |
|                                     | This activity is related to another hobby I have.                                 | 0.36                                                              | N = 215 (93.1%)                                                                 |
| Hedonism                            | I want to have fun.                                                               | 0.43                                                              | 0.4                                                                             |
|                                     | Participating makes me feel good about myself.                                    | 0.59                                                              | N = 219 (94.8%)                                                                 |
|                                     | I am passionate about the radon issue.                                            | 0.33                                                              | KMO = 0.57                                                                      |
| Achievement                         | I want to advance my career.                                                      | 0.26                                                              | 0.42                                                                            |
|                                     | I am seeking fame.                                                                | 0.26                                                              | N = 214 (92.6%)                                                                 |
| Power                               | I want to gain financial incentives.                                              | 0.75                                                              | 0.81                                                                            |
|                                     | I expect something in return.                                                     | 0.79                                                              | N = 217 (93.9%)                                                                 |
|                                     | I want to gain recognition and status.                                            | 0.77                                                              | KMO = 0.72                                                                      |
|                                     | Volunteering makes me feel important.                                             | excluded                                                          |                                                                                 |
| Face                                | I want to enhance my reputation.                                                  | 0.21                                                              | 0.37                                                                            |
|                                     | Other people think positively about my contribution to this project.              | 0.21                                                              | N = 199 (86.1)                                                                  |
| Social Expansion                    | I want to meet people with similar interests.                                     | 0.84                                                              | 0.8                                                                             |
|                                     | I want to be part of this volunteers' community.                                  | 0.61                                                              | N = 220 (95.2%)                                                                 |
|                                     | I want to socialize with other people.                                            | 0.83                                                              | KMO = 0.68                                                                      |

|                      |                                                                        |      |                 |
|----------------------|------------------------------------------------------------------------|------|-----------------|
| Security             | I want to keep myself secure and healthy.                              | 0.84 | 0.9             |
|                      | I want to live in secure surroundings.                                 | 0.84 | N = 223 (96.5%) |
| Conformity           | I was requested to participate by somebody.                            | 0.38 | 0.54            |
|                      | Other people I know are participating.                                 | 0.38 | N = 219 (94.8%) |
| Benevolence          | I am happy to help.                                                    | 0.87 | 0.87            |
|                      | It is a good thing to do.                                              | 0.77 | N = 225 (97.4%) |
|                      | I want to contribute to my community.                                  | 0.86 | KMO = 0.73      |
| Universalism, social | I want to improve our society.                                         | 0.77 | 0.81            |
|                      | I want to contribute to the well-being of others.                      | 0.85 | N = 226 (97.8%) |
|                      | I want to raise public awareness to the radon issue.                   | 0.69 | KMO = 0.7       |
| Help research        | with I want to contribute to science.                                  | 0.87 | 0.88            |
|                      | I want to contribute to the knowledge about the topic of this project. | 0.78 | N = 227 (98.3%) |
|                      | I want to contribute to scientific research.                           | 0.87 | KMO = 0.73      |
| Teaching             | I want to provide learning opportunities to others.                    | 0.69 | 0.8             |
|                      | I want to share my knowledge and experience.                           | 0.69 | N = 224 (97%)   |

Table 6.12 Constructs, Items, and Factor loadings of items (Intrinsic and Extrinsic motivations)

| Motivational type/<br>Construct | Items                   | Factor loading Principal axis | Cronbach's Alpha, N out of 231(%) |
|---------------------------------|-------------------------|-------------------------------|-----------------------------------|
| Intrinsic motivation            | Hedonism                | 0.53                          | 0.9                               |
|                                 | Security                | 0.45                          | N = 205 (88.7%)                   |
|                                 | Stimulation             | 0.69                          | KMO = 0.85                        |
|                                 | Social expansion        | 0.66                          |                                   |
|                                 | Benevolence             | 0.83                          |                                   |
|                                 | Universalism,<br>social | 0.87                          |                                   |
|                                 | Help with research      | 0.80                          |                                   |
|                                 | Self-direction          | 0.71                          |                                   |
|                                 | Teaching                | 0.81                          |                                   |
|                                 | Routine                 | excluded                      |                                   |
| Extrinsic motivation            | Achievement             | 0.72                          | 0.73                              |
|                                 | Face                    | 0.75                          | N = 215 (93.1%)                   |
|                                 | Conformity              | 0.32                          | KMO = 0.74                        |
|                                 | Power                   | 0.81                          |                                   |

Table 6.13 Motivation and engagement mentioned during group discussion

| Motivation and engagement    | No. of mentions |
|------------------------------|-----------------|
| achievement                  | 3               |
| conforming to teachers       | 1               |
| empowerment                  | 9               |
| general motivation           | 2               |
| interest to continue         | 1               |
| reward-based motivation      | 6               |
| security                     | 4               |
| interest in measurements     | 1               |
| interest in reference levels | 1               |
| interest in results          | 2               |
| self-esteem                  | 2               |