

Article

Setting the Scene for a Healthier Indoor Living Environment: Citizens' Knowledge, Awareness, and Habits Related to Residential Radon Exposure in Romania

Dacinia Crina Petrescu ^{1,*} and Ruxandra Mălina Petrescu-Mag ^{2,*}

¹ Faculty of Business, Babeş-Bolyai University, Horea St. no 7, 400174 Cluj-Napoca, Romania

² Faculty of Environmental Science and Engineering, Babeş-Bolyai University; Fantanele St. no 30, 400294 Cluj-Napoca, Romania

* Correspondence: crina.petrescu@tbs.ubbcluj.ro (D.C.P.); malina.petrescu@ubbcluj.ro (R.M.P.-M.)

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Abstract: The present research is based on the premise that people perceive radiation risks in different ways, depending on their cultural background, information exposure, economic level, and educational status, which are specific to each country. The main objective was to assess and report, for the first time, the Romanians' attitude (perceptions, knowledge, and behaviors) related to residential radon, in order to contribute to the creation of a healthier living environment. A convenience sample of 229 people from different parts of Romania, including radon prone areas, was used. Results profiled a population vulnerable to radon threats from the perspective of their awareness and perceptions. Thus, study results showed that most participants did not perceive the risk generated by radon exposure as significant to their health; only 13.1% of interviewed people considered the danger to their health as "high" or "very high". Additionally, it was found that awareness of radon itself was low: 62.4% of the sample did not know what radon was. From a practical perspective, the study shows that in Romania, increasing awareness, through the provision of valid information, should be a major objective of strategies that aim to reduce radon exposure. The present study takes a bottom-up perspective by assessing Romanian citizens' attitudes toward radon. Therefore, it compensates for a gap in the behavioral studies literature by providing practical support for radon risk mitigation and creating the premises for a healthier living environment.

Keywords: risk perception; awareness; attitude assessment; radon exposure; legislation; environment

1. Introduction

1.1. Radon as an Environmental Risk to People

Radon awareness and perception have been the focus of human health and environmental public debate over the last thirty years. Risk perception is mediated by beliefs about the existence and characteristics of the hazard and it is acknowledged to influence behavior change [1]. Radon is a naturally-occurring radioactive gas, present in soils, rocks, and water, that penetrates buildings, being, therefore, inhaled by the residents. In addition to the geological substrate (geological conditions), other main radon sources include anthropogenic factors, like building construction and materials, tap water, and living habits [2–4]. As radon is not stable and decays, it exposes the human body to radiation [5]. Radon is considered as one of the top four environmental risks to public health [6] and many occupational and epidemiological studies have investigated the links between chronic exposures to radon and lung cancer [7]. The World Health Organization (WHO) showed that between 2% and 12% of all lung cancer deaths in the EU were related to radon and that, for instance, the total number

of radon-related lung cancer deaths from France, Germany, and Switzerland was estimated to be about 3361 persons per year [8].

Scientific literature indicates that the most important radon contamination source is soil, from which it enters houses through cracks; additionally, building material and water are also radon contamination sources, generating together high concentrations if air exchange is reduced [9–11], thereby exceeding the WHO radon level recommendation—less than 100 Bq/m³ within housing. Nevertheless, WHO states that, even if this threshold is indicated, “no safe level of exposure can be determined”, as safety varies with individual health characteristics. The success of a policy (soft law) or of a legal measure (hard law) targeting human and environmental health depends on stakeholders’ acceptance, and this acceptance level increases if stakeholders are actively involved in the elaboration and implementation process.

Studies focused on Romania, especially on the Northwestern part (Transylvania), draw attention to the fact that about 600 lung cancer cases per year are due to radon inhalation, in a population of around 7,000,000 inhabitants [12]. Moreover, the results of a study by Cosma et al. [2] indicated that the average radon concentration calculated for the dwellings was 126 Bq/m³; this research was carried out between 2001 and 2011, based on samplings collected from a total of 1747 buildings located in 127 Romanian localities, mostly in villages (82% of them), excluding the Stei-Baita radon-prone area (from Bihor County, Romania). When Stei-Baita area measurements were included in the calculations (thus including 85% of the homes from Stei-Baita), 13% of all surveyed homes exceeded a concentration of 400 Bq/m³ as a consequence of the presence of former uranium mines near settlements [2,13,14]. Besides the close location of the village to the uranium mine (2–5 km), according to Cucos-Dinu et al. [13] the high levels of radon concentration indoors could be caused by the use of uranium mine tailings for building materials and the geological structure of the area. Since January 2017, a radon map for Romania was included in the European Radiological Data Exchange Platform (EURDEP) network for the exchange of radiological monitoring data between participating members [15].

At the global level, household environmental exposures often follow geographic patterns based on the quality of built environments, different climates, population behaviors, or the nature of geological formations [16]. People perceive different types of radiation risks in very different ways, depending on their cultural background, information exposure, economic level, and educational status [17,18]. Understanding of local communities’ perceptions and behaviors contributes to coping with environmental challenges [19,20]. Most of the studies on radon risk perception were conducted in developed countries, especially in the western world. The USA is the pathfinder, because in 1986 the U.S. Environmental Protection Agency called for the testing of all houses for radon and reducing indoor radon in homes with levels exceeding 4 picoCuries per liter [21]. Therefore, the radon prevention strategies should consider all these specific aspects and offer a combination of approaches. For example, in the USA, the measurement of radon is considered as a part of the real estate sales process [22], and in the Czech Republic [23], practices that test individual building sites prior to construction are mandatory to establish a radon index for the building site. In fact, the Czech Republic is, to the best knowledge of the authors, the first post-communist country that has undergone national radon programs, involving tens of thousands of inhabitants that are offered free measurements and subsidies for radon risk mitigation [24]. The Nordic countries have common regulations for eco-labeling (the Swan label) for building boards, which include a requirement to use the radium index: $C_{Ra} 100 \leq 1.0$ [25].

The International Commission on Radiological Protection (ICRP), the WHO, and the International Atomic Energy Agency (IAEA) supported countries to create and develop programs that addressed long-term risks from radon exposure in dwellings, public access buildings, and workplaces for any source of radon ingress. In 1990, the European Commission issued recommendations on advisory levels for radon in residential dwellings, as follows [26]: for existing buildings, a reference level for consideration of remedial action was imposed for an annual average radon gas concentration of 400 Bq/m³, while for future buildings, an annual average radon gas concentration was set at

200 Bq/m³. Directive 96/29/Euratom established basic safety standards (BSS) for the protection of the health of workers and the general public against dangers arising from ionizing radiation, but without including exposure to radon in dwellings [25]. The basic principles of protection against radon have been updated and consolidated in the BSS Council Directive 2013/59/Euratom, which will have to be transposed by 2018 [27]. According to Article 1 of the abovementioned Directive, its aim is to establish uniform basic safety standards for the protection of the health of individuals subject to occupational, medical, and public exposures from the dangers arising from ionizing radiation. Although radon measurements and human health protection programs already have a long history in some countries (for example, Sweden has had mandatory radon protection measures since the 1980s [28]), in other European countries (like Romania), research focused on radon measurements and the creation of radon maps is relatively recent [2,29], and, in this context, attitude studies, such as the present one, are relevant and useful.

For many European countries, including Romania, protection against radon started in the context of radon water regulation. At the end of 1998, Finland, Sweden, the Czech Republic, Russia, the Slovak Republic, and Romania had limits for radon in water. The reason why these countries introduced reference levels for radon in water is that they often relied on water supplies from wells drilled into crystalline bedrock, many times granites with enhanced uranium content [25]. High radon concentration levels above 1000 Bq/l, and even higher than 20,000 Bq/l, were found in several thousand wells in all of these countries [25]. These earlier radon water provisions were the foundation for supporting the transposition into Romanian legislation of Directive 2013/59, materialized in Law No. 301/2015 on establishing the requirements for the protection of human health as regards radioactive substances in drinking water (parameter value radon is 100 Bq/l; when radon concentration exceeds 1000 Bq/l, corrective actions must be carried out to ensure radiation protection, but extra analyses are not required) [30]. The importance of this legal provision is highlighted by the fact that a level of 1000 Bq/l of radon in tap water will increase, on average, the indoor air radon concentration by 100 Bq/m³ [31]. Reduction of radon concentration in water can be made through aeration of the room where water is stored and through dilution (mixing high radon concentration water with low radon concentration water), while water treatment installations have little effect [32]. However, radon water regulation is not the only activity for radon mitigation. There are various radon risk mitigation strategies that offer different ways to reduce the level of indoor and/or outdoor radon. These include soil suction, sealing cracks and openings, house pressurization, and heat recovery ventilators (HRV), and they vary largely in terms of complexity and costs.

1.2. From Risk Perception to Environmental and Radon Risk Perception—Conceptual Framework

The definitions of risk are abundant in the literature and many scholars have strived to find the most appropriate way of classifying different risks in various academic fields (social risk, economic risk, safety risk, environmental risk, or political risk). Therefore, due to its multidimensional and nuanced nature, a common definition of risk is difficult to develop. From an economic perspective, for example, “risk is a piece of information about a frequency distribution that, together with expected value, serves as an imperfect substitute for the density function in prescribing or explaining choice under uncertainty” [33]. The notion of risk involves, according to Stanley Kaplan and John Garrick both [34], uncertainty and some kind of loss or damage, and risk is “probability and consequence”. In order to have a uniform interpretation of risk-related concepts, the understandings hereafter are adopted. A “risk” is defined, according to the European Union guidelines, as the probability that an event will occur and generate negative consequences [35]. The hazard is a dangerous phenomenon, substance, human activity, or condition that may cause loss of life, injury, or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage [36]. Paul Slovic [37] emphasizes that the study of risk perception must examine how people characterize and evaluate hazards. Adopting the meaning used by O’Connor et al. [38], “risk perception” is understood in the current study as the perceived likelihood of negative consequences to oneself and society from

a specific environmental phenomenon, such as an in-house radon presence (an environmental risk). It is observed that the perception of risk from radon gas is positively related to other perceptions of the environment [39]. Environmental risk represents the probability to suffer potential negative effects due to changes in the environment [40]. Environmental risks form a distinct group and have specific features: high levels of uncertainty and uncontrollability, strongly delayed consequences, and consequences that occur at distant places and that are, therefore, often borne more by others than by the ones who caused them [41].

In the same way that value systems or the understanding of a need depend on collective and individual mental representations, and may differ over time and places [42], risk perception is conceptualized as a social construct and not as an objective property of a hazard or event ([43–45]). Thus, being, in part, a product of social experience, including communication about the consequences of potentially hazardous events [45], risk perception varies in terms of the degree to which people experience fear, lack of knowledge, or control [46]. Risk perception is considered a subjective assessment of the occurrence of an unfavorable event and of the concerns about the subsequent outcomes [47]; therefore, risk perception is relative to the observer, and it is a subjective thing, i.e., it depends upon who is looking [34].

In line with this last-mentioned understanding of risk perception, a specific study of Romanians' perception of radon risk is essential because the results reported in other countries cannot be extrapolated to the Romanian population (due to inherent cultural, economic, or social differences). Additionally, global and local scale analyses are complementary for risk management [48]. At the same time, such research supplies indispensable information to any awareness-educational campaign and to decision-makers responsible for designing and implementing health and environmental public policies by signaling that those who invest more in education are able to make better choices in critical situations [49].

The variables analyzed in the present study outline Romanian citizens' attitudes toward radon (as an environmental risk). For the present study, attitudes were investigated by taking into account radon awareness, radon risk perception, willingness to pay (WTP) for protection against radon, willingness to accept (WTA) actions for reducing radon risk exposure, and behaviors. Attitude can be beneficial or prejudicial both for individuals and at a societal level, impacting on radon (environmental) risk management and communication. Thus, for example, an attitude that incorporates high awareness of radon and radon risks, WTP and WTA actions for limiting radon risk exposure, and behaviors that lead to a reduction of radon levels in homes is likely to generate positive outcomes.

2. Research Aims

Despite addressing radon exposure risks by a substantial body of literature, few studies are dedicated to citizens' attitudes toward radon. Radon risk prevention and reduction are possible only if knowledge generated by medicine, chemistry, or physics is corroborated with that from social sciences, as humans are the main actors of the prevention and reduction measures [50]. Environmental risk perception is considered as a powerful determinant of people's environmental behavioral intentions [38] and, consequently, understanding perceptions, awareness, and actions becomes a pillar in the development of public policies and communication strategies focused on radon.

The present study takes a bottom-up perspective, being the first to assess Romanian citizens' attitudes toward radon and, thus, compensates for a gap in the behavioral studies literature by providing practical support for radon risk mitigation and creating the premises for a healthier living environment. Therefore, the goal of the article was to find out community-related information that would contribute to the prevention of radon consequences. At the same time, the availability of this information (such as low risk perceptions) justifies intervention measures designed to ease the transposition of the new European Union radon basic safety standards into national legislation. The main objective of the study was to assess and report the Romanians' attitude (perceptions, knowledge, and behaviors) related to residential radon.

An original feature of this investigation is brought by the aggregation of all studied variables (Table 1), dedicated to a geographical space (Romania) that faces radon risks. The risk is reflected by previous research that showed that indoor radon concentrations for about 30% of all studied dwellings exceeded the threshold of 300 Bq/m³, recommended as a reference level by the ICRP [51,52].

Table 1. Specific objectives of the study and investigated variables.

Objectives	Variables
(a) to evaluate radon-related <i>awareness</i> , which includes variables a.1 and a.2	a.1. awareness of the existence of this chemical element a.2. awareness of the existence of investigations (measurements) dedicated to the presence of radon in houses and its effects on human health
(b) to investigate indoor residential radon <i>risk perception</i> , taking into account the hereafter-mentioned variables (b.1. to b.9.) related to the present living environment of the interviewed people	b.1. extension of the consequences—present dimension b.2. extension of the consequences—future dimension b.3. rapidness of the manifestation of negative health consequences for those exposed to radon b.4. seriousness of death risk for those exposed to radon b.5. danger degree for the subject himself/herself if he/she is to be exposed to radon in his/her home b.6. danger degree for children (living there) if they are to be exposed to radon b.7. danger degree for neighbors if they are to be exposed to radon in their homes b.8. radon accumulation sources in houses b.9. level of radon accumulation in subject's house
(c) to evaluate the <i>WTP</i> and the <i>WTA</i> actions for reducing radon risk exposure, considering variables c.1 to c.3.	c.1. WTP to protect their homes against radon (through improvement works) c.2. WTA to be submitted to a free radon test c.3. WTA to start dwelling works to protect their homes against radon, using public funds
(d) to reveal the next mentioned <i>behaviors</i> (variables d.1. to d.4.), which are hazards that can influence the level of radon risk on people's health conditions	d.1. duration the windows are open for aeration in summer d.2. duration the windows are open for aeration in winter d.3. duration of their residence in the locality until present d.4. duration of intended future residence in the locality

3. Methods

Information about Romanian citizens' behavior, perceptions, and knowledge related to radon in residential environments was obtained using a survey that investigated the variables indicated in Table 1 and the questionnaire from Appendix A.

The evaluation of the way people relate themselves to radon starts with radon awareness, which should include, besides the awareness on this chemical element, awareness of radon measurements; the reason is that awareness of radon measurements influences the risk perception of the interviewed person (variables a.1, a.2). The perspective of Brewer et al. [53], in which the perceived risk has three components—perceived likelihood, perceived severity, and individual vulnerability—was incorporated in the present analysis (variables b.3, b.4, and b.5–b.7), and it was extended to create a more complex view of the perceived risk (for example, taking into account both the present and future dimensions of the extension of the consequences: variables b.1, b.2, b.8, and b.9). WTA, WTP, and other behaviors are possible indicators of the likelihood of acting toward risk reduction; this is the reason why they were included in the analysis (variables c.1–c.3 and d.1–d.4).

The sample was a convenience one and it contained 229 individuals from the western part of Romania, which also included a radon-prone area. Within the sample, 69% of participants were students, 13% of the entire sample was composed of students with an environmental education profile,

and 31% of the sample included non-students. Students were used as part of the sample because they are an important group in the society and they are, or will be, in the near future, players in the housing market, so their attitude toward housing-related health risks influences their house buying and maintenance behaviors. It is not rare to find samples made of students within the field of attitude studies [54–57]. The results cannot be extrapolated to the entire Romanian population, but they may serve as a reference point in the elaboration of future research dedicated to radon. Given these features of the sample, this study is a first attempt to address the issue of radon risk-perception, which may just be useful for more ambitious projects to be eventually carried out with a representative sample of the population.

Data was analyzed in Excel (Microsoft, Redmond, WA, USA) and SPSS (IBM Corporation, Armonk, NY, USA). The Mann-Whitney U test was used to compare differences between two independent groups when the dependent variable was either ordinal or continuous, but not normally distributed. The Wilcoxon signed ranks test was applied to analyze the difference in the median of a dependent variable between two related groups, and Spearman's rank-order correlation coefficient investigated the strength and direction of association that existed between two variables measured on at least an ordinal scale. The level of statistical significance was set at $p < 0.05$.

4. Results

4.1. Radon Awareness

The first condition to eliminate or reduce a risk is to be aware of it [58]. Consequently, the first tested variable was the awareness of the existence of this chemical element. The respondents had a very low awareness level of radon (37.6%, Table 2). This level is considered low in the context of the sample structure. One hundred percent of the students from the environmental profile faculty and 37.5% of the students from other faculties (economic and agricultural profiles) were aware of radon and nobody (0%) of the rest of the sample (non-students) was aware. There is a statistically significant difference concerning the awareness of radon between the environmental faculty profile students and the rest of the interviewed people. At the same time, awareness of radon measurements is extremely low (Table 2).

Table 2. Awareness of radon and radon measurements (percentages of total sample).

Variable/Category	Yes	No
a.1. Awareness of radon	37.6%	62.4%
a.2. Awareness of radon measurements	5.2%	94.8%

4.2. Perceptions Related to Radon

After people responded to the questions related to radon awareness (Table 2 and Appendix A), a brief explanation about radon was provided to them by the interviewer. Radon risk perception was very low within the analyzed sample. It was assessed by asking participants how many people they thought were/would be affected by radon (in the present, on one hand, and in the future, on the other hand). Thus, the number of persons considered (by the interviewed people) to be affected up until the present by radon is low and very low in the opinion of 92.6% of tested citizens, and the number of those that are likely to suffer in the future because of radon exposure is perceived as low and very low by 81.3% of interviewees (variables b.1. and b.2., Table 3).

Table 3. Radon risk perception (percentages of total sample).

Variable/Category						
		<i>Very few/none</i>	<i>Few</i>	<i>About half</i>	<i>Many</i>	<i>Very high number/All</i>
b.1.	Extension of the consequences—present dimension	69%	23.6%	2.6%	4.8%	0%
b.2.	Extension of the consequences—future dimension	49%	32.3%	7.4%	10%	1.3%
		<i>Never</i>	<i>After many years</i>	<i>After several years</i>	<i>In a few years, not many</i>	<i>Very quickly</i>
b.3.	Rapidness of health consequences manifestation for those exposed to radon	3.5%	16.2%	43.7%	31.4%	5.2%
		<i>Very small</i>	<i>Small</i>	<i>Average</i>	<i>High</i>	<i>Very high</i>
b.4.	Seriousness of death risk for those exposed to radon	5.2%	20.5%	39.3%	28%	7%
b.5.	Danger degree for himself/herself—health deterioration in case of radon exposure	18.3%	34.5%	34.1%	12.7%	0.4%
b.6.	Danger degree for children—health deterioration in case of radon exposure	18%	36.2%	28.8%	10%	7%
b.7.	Danger degree for neighbors—health deterioration in case of radon exposure	17%	35.4%	36.7%	10.5%	0.4%
b.8.	Level of radon accumulation in the house	53.3%	26.2%	19.7%	0.8%	0%
		<i>Wrong insulation</i>	<i>Contaminated construction materials</i>			
b.9.	Radon accumulation sources in houses	45.9%	79.85%			

People might perceive vulnerability to risks of various groups as being different. This is the reason why perception of the vulnerability of several groups was tested, using the Wilcoxon signed ranks test (Table 4, Appendix B). If they are found, significant statistical differences may indicate possible targets for communication campaigns. Regarding the perception of radon danger exposure in terms of health deterioration (variables b.5–b.7, Table 3), the respondents considered children as more vulnerable than the rest of the population ($p < 0.05$), but they did not make a difference regarding the risk between themselves and other people in the neighborhood, nor between themselves and children ($p > 0.05$; Table 4, Appendix B). While 17% of the sample evaluated health deterioration risk to be “high” and “very high” for children, only 13.1% and 10.9% of them, made the same appraisal for the risk concerning themselves and their neighbors, respectively. Consequently, protection of children health can be a motivational factor for stimulating behaviors oriented toward radon risk reduction within future communication strategies.

Concerning gender differences in relation to radon risk perception, similarly to Mainous et al. [39], who observed that women were more likely than men to perceive the risk from radon (3.5 times more), the present analysis revealed that Romanian women perceived a larger extension of the danger than men (variables b.1. and b.2. described in Table 1) ($p < 0.05$; Table 5, Appendix B). However, for the other variables (b.3.–b.8., described in Table 1), gender did not seem to be a significant factor in creating perception differences ($p > 0.05$).

As well, there was a statistically significant difference between the group of people who heard about radon prior to this survey and those who did not ($p < 0.05$; Table 6). The former group showed higher evaluations than the rest of the sample in the case of: perceived extension of the danger in terms of people affected (presently and in the future—variables b.1., b.2, Table 1) and seriousness of death risk (variable b.4, Table 1). This finding implies that, from a practical perspective, information and education campaigns may have a positive role in shaping a correct behavior related to radon risk. The same result was reported in a USA survey, where those who had already heard of radon believed that it posed health risk [39].

Table 4. Wilcoxon Signed Ranks Test results for comparison of perceived levels of radon risk between variables: (A), (B), and (C) *.

(A) Comparison between Variables b.6. and b.5.						
		Ranks			Test Statistics ^d	
		N	Mean Rank	Sum of Ranks	b.6. Risk disease children b.5. Risk disease subject	
b.6. Risk disease children b.5. Risk disease subject	Negative Ranks	32 ^a	40.38	1292.00	Z	−1.870 ^e
	Positive Ranks	49 ^b	41.41	2029.00	Asymp. Sig. (2-tailed)	0.061
	Ties	148 ^c				
	Total	229				
(B) Comparison between Variables b.7. and b.5.						
		Ranks			Test Statistics ⁱ	
		N	Mean Rank	Sum of Ranks	b.7. Risk disease neighbors b.5. Risk disease subject	
b.7. Risk disease neighbors b.5. Risk disease subject	Negative Ranks	17 ^f	18.65	317.00	Z	−0.036 ^j
	Positive Ranks	18 ^g	17.39	313.00	Asymp. Sig. (2-tailed)	0.972
	Ties	194 ^h				
	Total	229				
(C) Comparison between Variables b.7. and b.6.						
		Ranks			Test Statistics ⁿ	
		N	Mean Rank	Sum of Ranks	b.7. Risk disease neighbors b.6. Risk disease children	
b.7. Risk disease neighbors b.6. Risk disease children	Negative Ranks	44 ^k	35.86	1578.00	Z	−2.117 ^o
	Positive Ranks	26 ^l	34.88	907.00	Asymp. Sig. (2-tailed)	0.034
	Ties	159 ^m				
	Total	229				

* (A) b.5. Danger degree for himself/herself and b.6. Danger degree for children; (B) b.7. Danger degree for neighbors and b.5. Danger degree for himself/herself; (C) b.7. Danger degree for neighbors and b.6. Danger degree for children. ^a b.6. Risk disease children < b.5. Risk disease subject, ^b b.6. Risk disease children > b.5. Risk disease subject, ^c b.6. Risk disease children = b.5. Risk disease subject, ^d Wilcoxon Signed Ranks Test, ^e Based on negative ranks, ^f b.7. Risk disease neighbors < b.5. Risk disease subject, ^g b.7. Risk disease neighbors > b.5. Risk disease subject, ^h b.7. Risk disease neighbors = b.5. Risk disease subject, ⁱ Wilcoxon Signed Ranks Test, ^j Based on negative ranks, ^k b.7. Risk disease neighbors < b.6. Risk disease children, ^l b.7. Risk disease neighbors > b.6. Risk disease children, ^m b.7. Risk disease neighbors = b.6. Risk disease children, ⁿ Wilcoxon Signed Ranks Test, ^o Based on negative ranks.

Table 5. Mann-Whitney U Test results for differences between men and women regarding radon risk perceptions related to variables b.1.–b.8.

Ranks								
	Gender	N	Mean Rank	Sum of Ranks				
b.1. Extension of the consequences—present dimension	M	106	105.74	11,208.00				
	F	122	122.11	14,898.00				
	Total	228						
b.2. Extension of the consequences—future dimension	M	106	99.88	10,587.00				
	F	122	127.20	15,519.00				
	Total	228						
b.8. Level of radon accumulation in the house	M	106	124.97	13,247.00				
	F	122	105.40	12,859.00				
	Total	228						
Test Statistics ^a								
	b.1. Extension of the consequences—present dimension	b.2. Extension of the consequences—future dimension	b.3. Rapidness of health consequences manifestation	b.4. Seriousness of death risk	b.5. Danger degree for himself/herself	b.6. Danger degree for children	b.7. Danger degree for neighbors	b.8. Level of radon accumulation in the house
Mann-Whitney U	5537.000	4916.000	6074.000	6193.500	5805.500	5722.000	5575.500	5356.000
Wilcoxon W	11,208.000	10,587.000	11,745.000	11,864.500	11,476.500	11,393.000	11,246.500	12,859.000
Z	−2.311	−3.392	−0.841	−0.576	−1.393	−1.560	−1.889	−2.465
Asymp. Sig. (2-tailed)	0.021	0.001	0.401	0.565	0.164	0.119	0.059	0.014

^a Grouping Variable: Gender.

Table 6. Mann-Whitney U Test results for differences regarding radon risk perceptions related to variables b.1.–b.8. between the group of people who had previously heard about radon and the group of those who had not.

Ranks								
		Previous Radon Awareness	N	Mean Rank	Sum of Ranks			
b.1. Extension of the consequences—present dimension		Yes	86	128.04	11,011.50			
		No	143	107.16	15,323.50			
		Total	229					
b.2. Extension of the consequences—future dimension		Yes	86	136.48	11,737.00			
		No	143	102.08	14,598.00			
		Total	229					
b.4. Seriousness of death risk for those exposed to radon		Yes	86	135.41	11,645.00			
		No	143	102.73	14,690.00			
		Total	229					
Test Statistics ^a								
	b.1. Extension of the consequences—present dimension	b.2. Extension of the consequences—future dimension	b.3. Rapidness of health consequences manifestation	b.4. Seriousness of death risk	b.5. Danger degree for himself/herself	b.6. Danger degree for children	b.7. Danger degree for neighbors	b.8. Level of radon accumulation in the house
Mann-Whitney U	5027.500	4302.000	5979.500	4394.000	6008.000	6020.000	6136.500	5741.000
Wilcoxon W	15,323.500	14,598.000	9720.500	14,690.000	16,304.000	16,316.000	9877.500	9482.000
Z	−2.847	−4.132	−0.372	−3.793	−0.304	−0.277	−0.027	−0.926
Asymp. Sig. (2-tailed)	0.004	0.000	0.710	0.000	0.761	0.782	0.978	0.354

^a Grouping Variable: Previous radon awareness.

4.3. Willingness to Pay for and Willingness to Accept Actions to Reduce Radon Risk Exposure

WTP is generally understood as the amount of money an individual is willing to pay for a good (as this kind of improvement works to protect the homes against radon in this case). WTA is considered the amount of money that people accept to receive or the uncomfortable situations, in the present case, that people are willing to put up with in order to reduce radon risks. WTP and WTA are often investigated to predict behaviors related to environmental aspects [59–62]. Their inclusion in the present analysis aimed to find out if investigated citizens can be partners in future radon risk-mitigation strategies. Almost half of the sample was not willing to pay anything for protection against radon risks. This finding is in accordance with the low awareness of radon and the perception of a reduced radon risk (Tables 2 and 3). Around one third would pay a small amount of money for this purpose. However, most of them (71.6%) declared that if they had received public financial support, they would have started the works shortly (Table 7). A price of 55 Euro for improvement works may be estimated as high, given that the average gross salary in Romania is around 600 euro (Law No. 340/2015) [63] and that around 63% of the income is spent on food, non-alcoholic beverages, clothing, shoes, and utilities [64]. Almost all the interviewed citizens said “yes” to the idea of accepting a test if it was for free.

Table 7. Willingness to pay (WTP), for radon protection through improvement works; and willingness to accept (WTA), a free radon test and starting subsidized radon protection dwelling works (percentages of total sample).

	Variable/Category				
	0	1–55 Euro	55.1–120 Euro	120.1–240 Euro	>240 Euro
c.1. WTP for improvement works	41.0%	28.8%	12.2%	10.5%	7.4%
c.2. WTA a free radon test	Yes	No			
	96.9%	3.1%			
c.3. WTA subsidized works	Yes, in max 1 year	Yes, later 1.1–2 years	Yes, later than 2 years	No	
	71.6%	11.4%	3.9%	13.1%	

For Romanians, a statistically significant difference to pay for remediation works was found between those already aware of radon and the rest ($p < 0.05$, Table 8): those aware were willing to pay more for remediation works. However, WTA (a test or remediation works) was not sensitive to previous awareness ($p > 0.05$, Table 8), nor to gender ($p > 0.05$). At the same time, women declared they would pay higher amounts of money for radon house protection than men ($p < 0.05$), likely due to a higher concern for health issues.

Table 8. Mann-Whitney U Test results for differences regarding WTP for remediation works between people who previously heard about radon and those who did not.

	Ranks			
	Previous Radon Awareness	N	Mean Rank	Sum of Ranks
c.1. WTP to protect their homes against radon	Yes	86	136.72	11,758.00
	No	143	101.94	14,577.00
	Total	229		
Test Statistics ^a				
	c.1. WTP to protect their homes against radon	c.2. WTA to be submitted to a free radon test	c.3. WTA to start dwelling works to protect their homes against radon, using public funds	
Mann-Whitney U	4281.000	5992.000	5493.000	
Wilcoxon W	14,577.000	16,288.000	9234.000	
Z	−3.999	−1.085	−1.704	
Asymp. Sig. (2-tailed)	0.000	0.278	0.088	

^a Grouping Variable: Previous radon awareness.

Spearman's rho correlation coefficients were calculated and a positive correlation (with weak or medium strength) was observed between WTP for protection against radon and each of the perceptions related to risk—represented by variables b.1.–b.7. (Table 9). This means that the higher the perceived risk is, the stronger the WTP for radon protection becomes. A low perception of radon danger, in general, impacts people's WTP for protection and the observed low correlation (previously mentioned) is a confirmation of this *status quo*.

Table 9. Spearman's rho correlation coefficients for testing strengths and the direction of the relationship between variable c.1. and each of variables b.1.–b.7.

		Correlations								
		c.1.	b.1.	b.2.	b.3.	b.4.	b.5.	b.6.	b.7.	
Spearman's rho	c.1.	Correlation Coefficient	1.000	0.309 **	0.375 **	0.173 **	0.320 **	0.277 **	0.228 **	0.305 **
		Sig. (two-tailed)	0.000	0.000	0.000	0.009	0.000	0.000	0.000	0.000
		N	229	229	229	229	229	229	229	229

** Correlation is significant at the 0.01 level (two-tailed). * Correlation is significant at the 0.05 level (two-tailed). Legend: c.1. = WTP to protect their homes through improvement works; b.1. = Extension of the consequences—present dimension; b.2. = Extension of the consequences—future dimension; b.3. = Rapidness of the manifestation of negative health consequences; b.4. = Seriousness of death risk; b.5. = Danger degree for the subject himself/herself; b.6. = Danger degree for children; b.7. = Danger degree for neighbors.

4.4. Other Behaviors with Significant Impact on Radon Risk Exposure

Daily proper aeration influences the quality of the indoor environment by reducing radon concentration, and this is the easiest way to reduce radon accumulation [65,66]. If it is accepted that 'hazard' means the source of a risk [67], then specific behaviors are considered hazards that influence the level of radon risk on peoples' health conditions. Consequently, two seasonal (summer and winter) habits were tested, due to high temperature differences between them that greatly influence aeration propensity (Table 10). More than one-third (36.7%) of the sample indicated an aeration period longer than 12 h/day during summer, while a similar percentage aerated only between 6 and 15 min in winter (Table 10). A Wilcoxon test confirmed that there was a statistically significant difference between the time the windows stayed open during winter and summer (Table 11).

Table 10. Habits which influence radon risk exposure: aeration time in summer and winter, duration of peoples' residence in the locality until present, and the duration of intended future residence in the locality (percentages of total sample).

	0 min	1–5 min	6–15 min	16–30 min	31–60 min	1.1–2 h	2.1–4 h	4.1–8 h	8.1–12 h	>12 h
d.1. Aeration/day in summer	0.4%	0.4%	2.6%	4.4%	10.0%	7.4%	8.3%	15.3%	14.4%	36.7%
d.2. Aeration/day in winter	1.3%	10.5%	33.6%	24.9%	9.6%	10.0%	6.6%	2.2%	0.9%	0.4%
	≥1 year		1.1–5 years		5.1–10 years		>10 years			
d.3. Duration of residence in the locality until present	0.9%		21.8%		3.9%		73.4%			
d.4. Duration of intended future residence in the locality	6.1%		18.3%		2.6%		72.9%			

Residency duration in the same place can pose a significant negative impact on health in the case of existing threats. For the study sample, long periods of over 10 years dominate both history and intention of future residency: more than 70% of the sample lived for more than 10 years in the same house and intended to continue to stay there. Thus, health risks increase where radon is present in high concentrations.

Table 11. Wilcoxon signed ranks test results comparing aeration duration between summer and winter.

	Ranks			Test Statistics ^a		
	N	Mean Rank	Sum of Ranks	d.2. Aeration/day in winter d.1. Aeration/day in summer		
d.2. Aeration/day in winter d.1. Aeration/day in summer	Negative Ranks	209 ^b	110.25	23,042.00	Z	−12.548 ^c
	Positive Ranks	6 ^d	29.67	178.00	Asymp. Sig. (two-tailed)	0.000
	Ties	14 ^e				
	Total	229				

^a Wilcoxon signed ranks test, ^b d.2. Aeration/day in winter < d.1. Aeration/day in summer, ^c Based on positive ranks, ^d d.2. Aeration/day in winter > d.1. Aeration/day in summer, ^e d.2. Aeration/day in winter = d.1. Aeration/day in summer.

5. Discussion

Awareness level varies greatly across countries and studied populations. Similar to the findings of the current paper, a French study reported that 61.9% of the interviewed persons declared that they never heard about radon's presence within dwellings [68], and the French Cancer Barometer 2010 discovered that only 20% of people between 15 and 75 years old (within a random sample of 3359 individuals) knew that radon was a naturally-occurring gas [69]. Other research indicated findings contrary to those observed here: Duckworth et al. [70] showed that 97% of tested residents (from a total of 420 USA households) were familiar with radon, but 75% of respondents were not sure whether radon was a health hazard in their neighborhood. In Iran, almost 67% of respondents (from a total of 462 people, in a 2013–2014 survey) had heard about radon before the study [71].

Many studies revealed low awareness levels of radon risks, such as the ones found in this investigation where only 35% of tested Romanians considered the radon death risk “high” and “very high” (variable b.4., Table 3). In Canada, a country with almost 10% of lung cancer deaths caused by residential radon exposure, a survey on homeowners (on 152 persons) signaled that most respondents had little knowledge and concern about radon and its health effects [72]. In USA, more than a third of the subjects underestimated the seriousness of health effects of radon exposure, 39% disagreed that being around less radon would improve the long-term health of their children, and 52% were unsure whether radon could cause health problems [16]. Additionally, in an earlier investigation in the USA, Weinstein et al. [73] showed that respondents were not claiming that their risk was low because they did not smell radon (81.8% realized that it had no odor) or because they did not experience any physical symptoms. Opposite perceptions were also present: for instance, in Iran, the appraisals were higher, with 83.5% of respondents recognizing it as being hazardous and 34.5% identifying lung cancer as the main health outcome of exposure to radon [71].

Indoor radon exposure can be reduced through proper prevention or mitigation measures that can be grouped into: (i) construction/remediation actions (sub-slab depressurization, passive or active, with discharge open above the roof; natural ventilation; etc.); (ii) day-by-day habits (aeration through windows and doors); and (iii) exposure through the duration of living in the same place. Different studies have proved the effectiveness of the construction/remediation actions. In Finland, prevention construction measures helped in decreasing indoor radon concentration by 47% in provinces with the highest concentration and by 26% elsewhere in the country. Health Canada estimated that it cost around \$1000 USD to complete the renovations required to reduce radon risk in an average home [74], and in England, among 767 households that carried on remediation works, 52% of them paid less than 500 pounds [75]. Such results demonstrate that construction measures should be regarded as economic investments that also have positive effects in reducing moisture levels and contamination with other contaminants from the soil [76].

High levels of WTA-subsidized improvement works (observed in the present investigation) indicate that such actions can be implemented in radon-prone areas in Romania (variable c.3., Table 7), contributing to the reduction of radon exposure. The results cast light on positive attitudes of

Romanians toward protection if the monetary problem was solved with the aid of public intervention. Other studies took into account a radon level test paid by users and revealed various attitudes relating to WTP and WTA. In Iran, 70% of the people already aware of radon risk were willing to test their houses [71]; in the USA, most were unsure (8%) or were not planning (48%) to conduct radon screening on their own [70]; and in Canada, only 4% of the population had ever tested their homes for radon [77].

6. Conclusions

This study presents itself as a frame of reference for decision-makers to develop community-based solutions in relation to radon—in accordance with the proximity principle. This principle requires the adoption of decisions as close as possible to citizens—grounded on an understanding of what people think, feel, and do [78]. To this end, the research offers a complex image of the investigated people, structured on four coordinates: (i) radon awareness, (ii) risk perception, (iii) WTP and WTA, and (iv) other behaviors with a significant influence on the level of radon risk on peoples' health conditions.

These results revealed a potentially vulnerable population to radon exposure, especially in light of their lack of awareness of radon health risks. Generally, it can be stated that radon is not perceived of as a relevant health risk by most tested people, as long as only a reduced share of them consider the degree of danger regarding the deterioration of their own health as “high” and “very high” in cases in which they were exposed to radon. Radon awareness and perceptions, which have predominantly low levels among respondents, clearly state the need for information adapted to the specificity of the Romanian population. WTP for protection against radon was low, but the situation was partially compensated for by a very high willingness to accept a test and willingness to undergo remediation works in case the financial burden was assumed by the state or another entity. Aeration of the house, largely adopted by surveyed individuals, is a helping pillar in reducing radon exposure for the population at risk who has limited financial resources with which to cope with it. However, in general, high awareness, perceptions of radon threats, intentions, etc., are not a guarantee that a behavior directed toward the mitigation of risk will be put into practice by the holders of these perceptions, as other factors (such as situational obstacles) might intervene [79]. If these reported low levels of awareness were obtained from a sample mostly made of educated people, with high access to information, it can be assumed that the awareness is even lower within the general population, making it all the more necessary to develop education-information campaigns or other measures that aim to create a healthier indoor living environment for citizens. Reduced awareness (Table 2) is the engine that generates such perceptions related to radon risk. Therefore, increasing awareness should be an important objective of programs targeting radon risk-mitigation, along with the funding, measurement, or implementation of technical solutions. The evaluation of the radon threat and of radon levels can be used as an indicator of intentions to act in order to reduce radon indoor accumulation, as was mentioned by Weinstein and Sandman [79].

On the basis of this first assessment of Romanian citizens' attitude toward radon, the authors propose a further extension of the study by using a representative sample of the population at the country level. In addition, it would be also useful to focus on the work environment (besides the residential one tested here).

These results, corroborated by the Romanian radon map, support the development of *de lege ferenda* proposals, which is the next desirable stage, in order to completely fulfil the objectives of Directive 2013/59/Euratom. Future research should focus on how to create a mix of instruments—legal, economic, and technical—to reinforce the total effects of each component more effectively, leading to beneficial consequences for every national specific context. Such studies should also investigate to what extent each instrument can contribute to the total mitigation.

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Appendix A

Appendix A contains the questions used in the survey.

Questions used in the survey to study the selected variables:

Variable	Question
a.1. awareness on the existence of this chemical element →	Have you heard about radon? If yes: What can you tell about it?
a.2. awareness on the existence of investigations (measurements) dedicated to the presence of radon in houses and its effects on human health →	Were radon measurements or tests developed in the region where you live?
b.1. extension of the consequences—present dimension →	In your opinion, how many people in your region became ill because of radon?
b.2. extension of the consequences—future dimension →	In your opinion, how many people in your region will become ill in the future because of radon?
b.3. rapidness of the manifestation of negative health consequences for those exposed to radon →	If people live in an area where they are exposed to radon, how long does it take until their health is damaged due to radon?
b.4. seriousness of death risk for those exposed to radon →	If people live in an area where they are exposed to radon, how serious is the death risk for them?
b.5. danger degree for the subject himself/herself if he/she is to be exposed to radon in his/her home →	If you lived in an area where you would be exposed to radon, how high/low would be for you the danger degree to become ill?
b.6. danger degree for children (living there) if they are to be exposed to radon →	If your children/grandchildren lived in an area where they would be exposed to radon, how high/low would be for them the danger degree to become ill?
b.7. danger degree for neighbors if they are to be exposed to radon in their homes →	If you lived in an area where you would be exposed to radon, how high would be for your neighbors the danger degree to become ill?
b.8. radon accumulation sources in houses →	Which are the causes that lead to the accumulation of radon in houses? (multiple choice question)
b.9. level of radon accumulation in subject's house →	In your opinion, how high is the radon level inside your home?
c.1. WTP to protect their homes against radon (through improvement works) →	How much would you pay/year to protect your house against radon?
c.2. WTA to be submitted to a free radon test →	Are you willing to accept a free test in order to determine the level of radon in your home?
c.3. WTA to start dwelling works to protect their homes against radon, using public funds →	Are you willing to start dwelling works to protect your home against radon, using public funds? If yes, how soon?
d.1. duration the windows are open for aeration in summer →	How long do you keep your window open for aeration during summer time?
d.2. duration the windows are open for aeration in winter →	How long do you keep your window open for aeration during winter time?
d.3. duration of their residence in the locality until present →	Since when have you been living in this locality?
d.4. duration of intended future residence in the locality →	How long do you intend to keep on living in this locality?

Appendix B

Appendix B contains Tables 4 and 5.

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