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A cost-effectiveness analysis of lowering residential radon levels in Sweden—Results from a modelling study

Mikael Svensson [a,*], Lars Barregård [b], Gösta Axelsson [b], Eva M. Andersson [b]

[a] Health Metrics, The Sahlgrenska Academy, University of Gothenburg, Box 414, SE 405 30, Gothenburg, Sweden
[b] Department of Occupational and Environmental Medicine, University of Gothenburg, Gothenburg, Sweden

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ABSTRACT

Purpose: Residential exposure to radon is considered as the second leading cause of lung cancer after smoking. The purpose of this study was to conduct a cost-effectiveness analysis of reducing the indoor radon levels in Sweden from the current reference level of 200 Bq/m^3 to the WHO suggested reference level of maximum 100 Bq/m^3.
Methods: We constructed a decision-analytic cost-effectiveness model using input data from published literature and administrative records. The model compared the increase in economic costs to the health benefits of lower indoor radon-levels in a Swedish policy context. We estimated the cost per life-year and quality adjusted life year (QALY) gained and assessed the robustness of the results using both deterministic and probabilistic sensitivity analysis.
Results: Including (excluding) costs of added life years the cost per QALY for existing homes was €130,000 (€99,000). For new homes the cost per QALY including (excluding) costs of added life years was €39,000 (€25,000).
Conclusions: The results indicate that it is not cost-effective to reduce indoor radon levels from 200 Bq/m^3 to a maximum of 100 Bq/m^3 in existing homes, whereas it is cost-effective for new homes.

1. Introduction

Lung cancer is among the most fatal cancers with an estimated 5-year survival rate in the European Union of 13%. Globally it is estimated that lung cancer accounts for approximately 20% of all cancer deaths [1,2]. The economic burden of cancer, measured as the societal direct and indirect costs of cancer, is estimated to be around 1% of total Gross Domestic Product (GDP) in the European Union countries. Lung cancer is the most costly form of cancer and about 15% of the total cancer costs is attributed to lung cancer [3].

The primary cause of lung cancer is cigarette smoking, with the second cause being residential exposure to radon. The lung cancer risk from radon affects both smokers and non-smokers, although the elevated risk primarily affects smokers [4,5]. Radon is a radioactive gas and is produced by the breakdown of uranium normally found in rock, soil, and water. Radon levels therefore vary geographically due to varying uranium amounts in the underlying rock. Radon can accumulate in buildings due to ground leakage and radon-contaminated building materials (e.g. concrete). Another risk is that radon spreads to household water from deep drilled wells, and further to indoor air e.g. from showers.

There are a large number of case-control studies, mainly from Europe and the US, on the relationship between residential exposure to radon and the risk of lung cancer. Based on data from 13 European case-control studies evidence was provided that there is a linear dose-response relationship between exposure to radon and lung cancer risk, and that residential radon in homes accounts for about 9% of all deaths from lung cancer in Europe [6].

Different radon remediation actions can be taken to reduce the concentration of indoor radon, and the appropriate measure depends on the source of radon. Remediation actions include reducing the influx of ground-level leakage, removing radon-contaminated building materials, and filtering household water (if there is leakage from groundwater to deep drilled wells). For construction of new homes the most important remediation action is to secure air-tight ducts through slab, floor and basement walls to prevent leakage of radon from the ground.

Radon remediation costs varies with the type of house (detached or apartment buildings), and importantly, also depend on whether or not conducted in existing or new homes. It is costlier to reduce radon levels in existing homes and if the source of radon is ground leakage or from building material, as opposed to contaminated

* Corresponding author.
E-mail address: mikael.svensson.2@gu.se (M. Svensson).

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water. In new buildings the cost is mainly dependent on the type of construction (slab, crawlspace, or basement) [7].

Most countries have some form of national guideline for radon remediation and acceptable concentrations of indoor radon. The guidelines can be in the form of an action level with enforced requirements for remediation measures and/or a warning/reference level with recommendations for remediation [8]. Reference levels are commonly in the range between 200–400 Becquerel per cubic metre (Bq/m^3) [9]. Due to an increasing awareness of the relationship between indoor radon and lung cancer, the World Health Organization (WHO) has changed their recommendations and suggests a reference level of 100 Bq/m^3 [4].

To comply with a reference level of a maximum of 100 Bq/m^3 would imply a substantial additional cost, and it is of interest to evaluate if the assumed health benefits can motivate a revision of national guidelines. Economic evaluation methods in the form of cost-benefit and/or cost-effectiveness analysis are tools to assess if the benefits of a policy are substantial enough to motivate the costs from an efficiency perspective. Cost-benefit analysis (CBA) and cost-effectiveness analysis (CEA) differ in that the former compares benefits and costs expressed in monetary metrics, whereas the latter (CEA) compares the costs in a monetary metric to some non-monetary benefit metric. Previous economic evaluations of radon remediation have shown slightly mixed results that vary across geographical contexts. One important reason for varying cost-effectiveness in different contexts is that the cost of radon mitigation investments differs between regions due to varying levels and sources of radon.

One of the more recent studies we have identified using up to date methods for CEA is an evaluation of remediation investments in the UK. Based on the cost per quality adjusted life year (QALY) gained it was reported that it would be highly cost-effective to reduce indoor radon concentration levels in new buildings, but not cost-effective in existing buildings [10]. An economic evaluation of radon mitigation in Denmark concluded that the radon mitigation policies suggested by the Danish government do not pass a benefit-cost test [11]. An exception to the findings from the UK and Denmark is a CEA carried out in the German context, where the authors concluded that it would be cost-effective to introduce legal regulations with mandatory screening and mitigation for indoor radon levels above 100 Bq/m^3 [12].

The aim in this paper was to add to this literature and to conduct a CEA in the Swedish context to evaluate the cost-effectiveness of implementing radon remediation to reach the WHO reference levels of 100 Bq/m^3 in Swedish homes. This study adds to the literature in the form of a CEA of a new geographical context with high levels of indoor radon in a European context. An addition is also the distinction between radon remediation for different sources of radon; ground, building material, or from water. Further, we use data from the most up-to-date epidemiological findings that linked indoor radon levels to lung cancer deaths in the Swedish context together with a national review of prevention costs [13].

Currently, the reference level for existing homes in Sweden is 200 Bq/m^3, whereas for new homes 200 Bq/m^3 is an action level. Specifically, Swedish regulations state that for existing homes, property owners are advised to invest in radon remediation if measurements show a radon level significantly above 200 Bq/m^3. For new buildings, property owners are not only advised, but mandated, to invest in radon remediation if levels are above 200 Bq/m^3. However, it should be noted that there is no legal mandate to carry out measurements (if done, these are recommended to be carried out for 2–3 months between October and April).

Among existing Swedish homes it has been estimated that around 16–18% of houses and 5–8% of apartment buildings have indoor radon levels above 200 Bq/m^3, which are substantially higher shares than in most European countries [14,15]. The higher indoor radon levels in Sweden could imply larger health benefits of radon remediation. On the other hand, the prevalence of smoking in Sweden is among the lowest in the world, which may indicate smaller potential benefits from radon remediation [16].

2. Method

2.1. The decision analytic model

We constructed a decision analytic model comparing two scenarios: (a) status quo (reference level at 200 Bq/m^3) with the current distribution of indoor radon levels, and (b) reduce the national recommendation to 100 Bq/m^3 and implement the necessary investments to reach this target. We conducted the analysis in existing and new homes separately due to the differences in radon remediation costs.

We applied the model using both a more restrictive perspective only including the direct remediation and health care costs as well as a broader societal perspective where we also included future additional health and social cost consequences due to the gained life expectancy due to the lower cancer risks [17]. In the base-case (or "reference case"), we assumed a life-length of 25 years for the necessary investments to reduce radon levels. This assumption is based on technical reports from the Swedish National Board of Housing, Building and Planning regarding the life-length of radon remediation [7]. It has been suggested that the life-length should be based on the life expectancy of remediation measures or on the mean manifestation period [18]. Yet a complicating issue regards the latency of the beneficial effects of radon remediation [19]. In our base-case we assumed a left-skewed (negative gamma) distribution where the benefits stream profile gradually increases in magnitude and reaches the maximum at 25 years. In sensitivity analyses we varied this from 15 to 30 years.

In a CEA that extends over time (more than one year) it is advised to take the timing of costs and effects into account using a positive social discount rate, i.e. future consequences (costs and health benefits) are valued less than current consequences. We used a social discount rate of 3 percent, which is in line with Swedish recommendations for health economic evaluations as well with the recommendations by e.g. the US Panel on cost-effectiveness [20,21].

2.2. Informing the model – costs and health benefits

To populate the model, we need information about costs and health benefits. Regarding costs, the status quo option by definition implies no cost changes compared to the current situation. The cost data on radon remediation was based on a review by the Swedish National Board of Housing, Building and Planning [7]. The costs differ depending on whether or not we consider new or existing homes, as well as depending on the source of the radon. For existing homes, the possible sources of radon are from the soil, building material, or the ground water. For new homes, we differentiate investments depending on the construction type (slab, crawlspace or basement), where the remediation cost is highest for crawlspace (e.g. securing that radon does not leak up into the crawlspace).

It is estimated that 400,000 residential homes and 230,000 apartments in Sweden have radon-levels above 100 Bq/m^3 and based on the distribution of radon sources and the remediation costs it has been estimated to cost additionally approx. 23 billion Swedish kronor (SEK, approx. €2.46 billion) to reach the target of a maximum level of indoor radon of 100 Bq/m^3. For new homes, it has been estimated to cost additionally approx. 187 million SEK per year (€20 million).

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