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# REGULATORY IMPACT OF POSSIBLE RADON PREVENTION MEASURES IN NEW BUILD HOMES IN IRELAND

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ESRI ECONOMIC & SOCIAL
RESEARCH INSTITUTE

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# ABBREVIATIONS

| | |
|---|---|
| BER | Building Energy Rating |
| BRU | Behavioural Research Unit |
| CEA | Cost effectiveness analysis |
| CSO | Central Statistics Office |
| CUA | Cost utility analysis |
| DHLGH | Department of Housing, Local Government and Heritage |
| DPM | Damp-proof membrane |
| ED | Emergency Department |
| EPA | Environmental Protection Agency |
| ESRI | Economic and Social Research Institute |
| HPO | Healthcare Pricing Office |
| HIPE | Hospital Inpatient Enquiry |
| HRA | High radon area |
| ICER | Incremental cost effectiveness ratio |
| NCR | National Cancer Registry |
| PHE | Public Health England |
| QALE | Quality Adjusted Life Expectancy |
| QALY | Quality Adjusted Life Year |
| RAA | Radon affected area |
| RIA | Regulatory Impact Analysis |
| TGD-C | Technical Guidance Document C |
| WHO | World Health Organisation |

# EXECUTIVE SUMMARY

## OVERVIEW

The purpose of this report is to undertake an ex-ante evaluation of the cost effectiveness of alternative radon prevention measures for new build properties in Ireland. Radon is a naturally occurring gas that primarily enters a building by seeping through the ground floor. Radon is the predominant source of radiation in Ireland, the second most prominent cause of lung cancer after smoking, and the number one cause of lung cancer amongst people who have never smoked. One of the most common prevention methods for new buildings is the installation of an airtight radon-proof membrane across the foundation.

In this report, we focus on the installation of radon-proof membranes as a preventive measure in new build homes in Ireland. Based on discussions with the Environmental Protection Agency (EPA) and the Department of Housing, Local Government and Heritage (DHLGH), we examine the cost effectiveness of a number of alternative membrane options in new build properties in Ireland, in order to inform future updates to the Building Regulations. The policy options evaluated are:

- A requirement for sealed radon membranes in all areas, including in those parts of the country not designated as high radon areas (option 1);
- A requirement to seal damp-proof membranes in non-high radon areas (option 2);
- A requirement for sealed damp-proof membranes in all areas (option 3).

The baseline (status quo) requirement is sealed radon membranes in high radon areas, and unsealed damp-proof membranes in non-high radon areas. The three policy options therefore vary both the population covered and/or the type of membrane. Other radon protection measures such as the installation of standby radon sumps, increased ventilation, active soil depressurisation etc. are not considered in this analysis.

## DATA AND METHODOLOGY

Cost effectiveness (CEA) and cost utility analysis (CUA) techniques are used to analyse the costs, benefits and other impacts for each policy option, relative to the baseline (status quo) option. In a CEA, outcomes are expressed in terms of life years gained, while in a CUA, the outcomes expressed in terms of quality-adjusted life years gained. A QALY is a year of life adjusted for its quality. The QALY aims to incorporate quality and quantity of life in one measure. The analysis results in summary measures, a cost per life year gained, or a cost per QALY. A larger cost per life year gained, or QALY, indicates a less cost effective intervention. Historically, in Ireland, health interventions below the threshold €20,000-€45,000 per QALY have been considered cost effective. As far as possible, a societal perspective is adopted, whereby costs and benefits to society at large rather than the Exchequer or the healthcare system, are quantified. For example, costs include lung cancer treatment costs, as well as radon-proof membrane material and installation costs incurred by developers and builders. To analyse quantifiable costs and benefits, a cohort-based simulation model (with the population disaggregated by five-year age band, sex, smoking status and radon risk area) is employed. Data are obtained from a variety of sources, including published studies, administrative and survey data, and industry sources.

## DISCUSSION

The evaluation of the three alternative policy options for radon prevention in new build homes in Ireland found that all three options would be considered cost-effective under current threshold values for the evaluation of health interventions in Ireland, with the third policy option (sealed damp-proof membranes in all areas) cost-saving. Most sensitivity analyses that varied assumptions about key parameters (e.g. rate of population growth, material and installation costs, etc.) did not change the overall conclusions from the main results. Sensitivity analyses revealed that the cost effectiveness of the third policy option was highly sensitive to an alternative assumption about the protection offered by radon vs. damp-proof membranes (although the data underlying this assumption were illustrative rather than evidence-based).

As with any cost effectiveness analysis, the results are dependent on the specification of the baseline and alternative policy options, and the underlying assumptions that are made about the various parameters inputted into the model. Due to the absence of appropriate data, it was not always possible to incorporate assumptions about potentially important costs and benefits (e.g. the productivity gains associated with lung cancer cases prevented due to radon protection measures). More generally, many of the parameters used in this model are based on data from other countries (e.g. on time spent at home). While every effort has been made to source data from Ireland, this was not possible and data from other countries had to be used instead.

A potentially crucial source of costs and benefits that is not quantified in this analysis relates to the quality of the installation of membranes. The costs of the membranes examined in this study cover the material and installation costs only, and the benefits assume a common benefit across sealed radon and damp-proof membranes to take account of variability in the quality of installation across sites. Consultation with industry representatives, as well as those involved in previous cost effectiveness analyses in the UK, stressed the importance of the quality of the installation of membranes (i.e. airtight sealing), rather than the type of membrane per se, for protection against indoor radon. While perfect installation should ensure a significantly lower radon level in a home, in practice errors in installation or damage during construction can result in ineffective protection. This warrants training of site staff and builders, as well as the need to measure radon, post-construction, when the building is in use. More widespread inspection of sites during and after construction may also be required.

# CHAPTER 1

# Introduction

## 1.1 INTRODUCTION

The purpose of this report is to provide an ex-ante analysis of the likely regulatory impact of alternative radon prevention measures for new build properties in Ireland. Radon is the predominant source of radiation in Ireland, the second most prominent cause of lung cancer after smoking, and the number one cause of lung cancer amongst people who have never smoked (EPA, 2022). One of the actions of the current phase of the National Radon Control Strategy is to carry out research on additional radon prevention measures in new build properties, in order to inform updates to Technical Guidance Document C (TGD-C) (EPA, 2019). Under the programme of research on environmental economics at the Economic and Social Research Institute (ESRI), funded by the Environmental Protection Agency (EPA), the current project seeks to examine the cost effectiveness of a number of radon prevention options in new build properties in Ireland, in order to inform future updates to the Building Regulations. One of the most common prevention methods for new buildings is the installation of an airtight radon-proof membrane across the foundation. Based on discussions with the EPA and the Department of Housing, Local Government and Heritage (DHLGH), we focus in this report on the installation of radon-proof membranes as a preventive measure in new build homes in Ireland.

Our approach is informed by Ireland's guidance on Regulatory Impact Analysis (Department of the Taoiseach, 2009), parameters set out by the Department of Public Expenditure and Reform for public expenditure appraisals (Department of Public Expenditure and Reform, 2019), and national guidance on appropriate methods for evaluating health interventions (Health Information and Quality Authority, 2019).

In this chapter, we provide some further background on the scope of the current project (Section 1.2); the policy problem and objective (including a review of the health effects of radon and how radon risk varies across Ireland) (Section 1.3); the specification of the baseline and alternative policy options (Section 1.4); the methods we use (i.e. cost effectiveness and cost utility analysis) to evaluate the different options (Section 1.5); and previous research (both Irish and international) on the cost effectiveness of radon prevention measures in new build homes (Section 1.6).

## 1.2 SCOPE OF THE ANALYSIS

The broad steps set out for a regulatory impact assessment (RIA) in Department of the Taoiseach (2009) are listed below:

1. Summary of RIA;
2. Statement of policy problem and objective;
3. Identification and description of options;
4. Analysis of costs, benefits and other impacts for each option;
5. Consultation;
6. Enforcement and Compliance;
7. Review;
8. Publication.

In this report, we aim to contribute evidence for steps 2, 3 and 4 in this framework.

## 1.3 POLICY PROBLEM AND OBJECTIVE

Radon is a naturally occurring inert gas formed by the radioactive decay of uranium in the earth's crust. Radon moves freely through the soil as a gas, where it is then diluted to harmless concentrations in the atmosphere. Radon primarily enters a building by seeping through the ground floor. In particular, radon is transported into homes:

> *through cracks in solid floors and walls below construction level; through gaps in suspended concrete and timber floors and around service pipes; through crawl spaces, cavities in walls, construction joints, and small cracks or pores in hollow-block walls* (Appleton, 2007).

Other sources of indoor radon include building materials and the radon concentrations of groundwater used for domestic drinking water, although these are considered lower risk sources than radon gas in the ground beneath the building (Health Protection Agency, 2009; WHO, 2009). Radon is the predominant source of radiation exposure in Ireland (estimated to be 55 per cent of the dose received) (EPA, 2022). By international standards, Ireland has relatively high indoor radon concentrations (WHO, 2009),[1] with an average (geographically-weighted) indoor radon concentration of 77 Bq/m$^3$ (Dowdall et al., 2017).[2] The population-weighted average radon concentration in Ireland is 98 Bq/m$^3$ and has increased over time, reflecting changes in the distribution of the population across geographic

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[1] See Table 4 in WHO (2009) for a comparison of indoor radon levels across countries.

[2] Radon concentration refers to the activity of radon gas in terms of decays per time in a volume of air. The unit of radioactivity concentration is given in Becquerel per cubic metre (Bq/m$^3$) (WHO, 2009).

areas of the country (Murphy et al., 2021). In contrast, the population-weighted average radon concentration in the UK was estimated to be 20 Bq/m$^3$ in 2005 (Health Protection Agency, 2009).

Radon is classified as a Group 1 carcinogen (International Agency for Research on Cancer, 1988). It is the second most prominent cause of lung cancer after smoking, and the number one cause of lung cancer amongst people who have never smoked (Bräuner et al., 2012; WHO, 2009). Using pooled data from 13 European case-control studies, Darby et al. (2006) estimated a linear dose-response relationship between radon and lung cancer risk, with the risk of lung cancer increasing by 16 per cent for every 100 Bq/m$^3$ increase in radon concentration. In addition, Darby et al. (2006) found no evidence of a threshold value, with the dose-response relationship holding for individuals whose homes measured an indoor radon value less than 200 Bq/m$^3$ (200 Bq/m$^3$ is the reference level in Ireland, above which remedial action is recommended; EPA, 2022). Furthermore, the dose-response relationship held regardless of the age, sex or smoking status of the individual.

Lung cancer is the leading cause of cancer deaths in Ireland, with an estimated five-year survival rate of 24 per cent (National Cancer Registry, 2021). Roughly 2,700 people are diagnosed with lung cancer every year in Ireland (National Cancer Registry, 2021), and smoking is the main cause of lung cancer (O'Keeffe et al., 2018). Internationally, the proportion of lung cancer cases estimated to be attributable to radon ranges from 14-17 per cent (Gaskin et al., 2018a). In Ireland, it has been estimated that approximately 350 lung cancer cases per annum are due to indoor radon exposure (Murphy et al., 2021).

The World Health Organisation (WHO) recommends that a national reference level (maximum accepted radon concentration level in a residential building, above which remedial action is recommended) should be less than 300 Bq/m$^3$ (WHO, 2009). This is reiterated in the EU Basic Safety Standards Directive 2013.[3] Ireland's national reference level for homes is set at 200 Bq/m$^3$, with the Ionising Radiation Regulations 2019[4] defining high radon areas as an area where more than 10 per cent of domestic dwellings in that area will have radon concentrations above the national reference level. The potential for high radon levels is partly determined by local geology including the concentration of uranium and the porosity and/or degree of fracturing in the near-surface geological features (Hodgson et al., 2019).

In Ireland, a high spatial resolution radon risk map has been developed, based on a combination of over 30,000 indoor radon measurements and relevant geological

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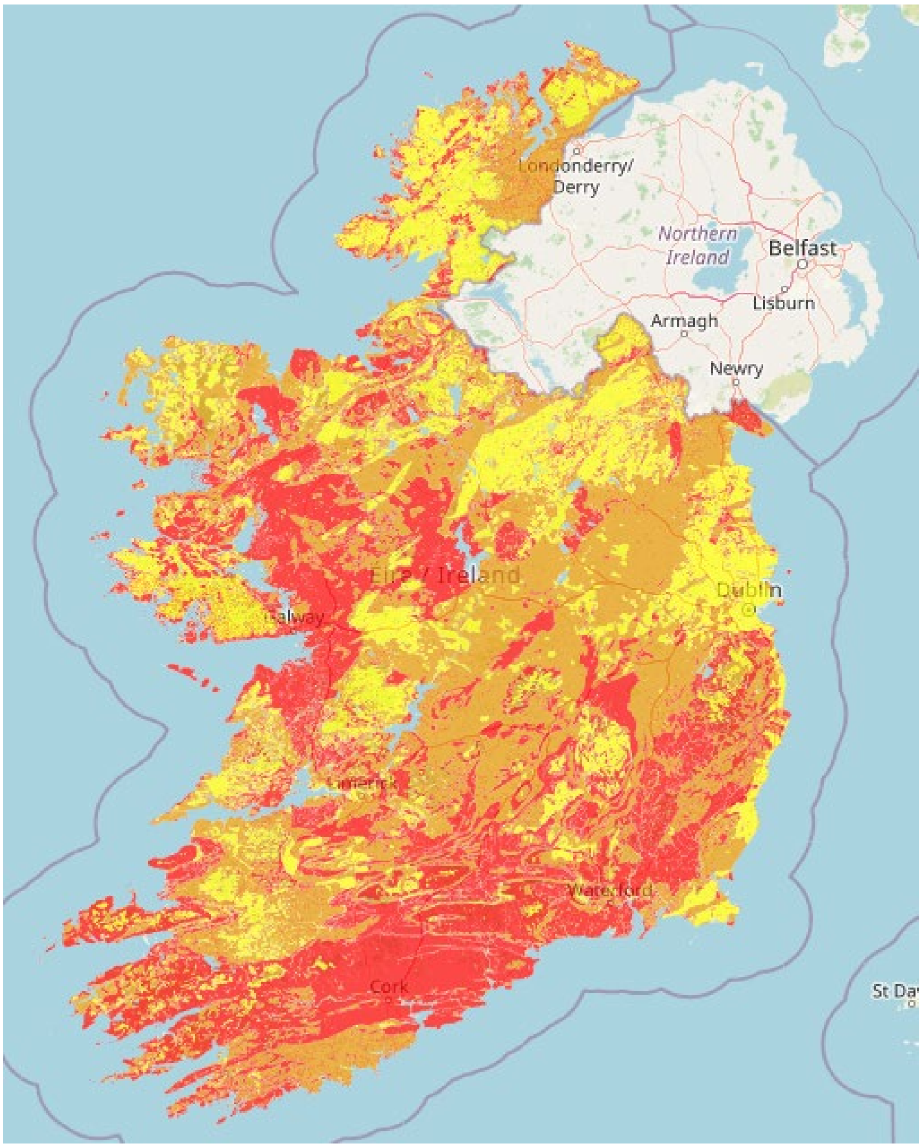
[3] EU Basic Safety Standards Directive 2013 Council Directive 2013/59/EURATOM.

[4] Radiological Protection Act 1991 (Ionising Radiation) Regulations 2019, S.I. No. 30/2019.

information. A 2017 study used statistical methods to predict the probability of having an indoor radon concentration above the national reference level of 200 Bq/$m^3$. The results showed that the country may be divided in three main radon risk categories: high, medium and low, with the probability of having an indoor radon concentration above 200 Bq/$m^3$ found to be 19 per cent, 8 per cent and 3 per cent in each area, respectively. Approximately 10 per cent of the population are estimated to be exposed to indoor radon levels in excess of 200 Bq/$m^3$ (Elío et al., 2017). Subsequent design work by the Behavioural Research Unit (BRU) at the ESRI advised that a map that communicates risk using numeric frequencies, with three categories of risk, using a typical yellow-to-red colour scheme and with search functionality would benefit map users, increase perceptions of risk from radon and encourage testing (Timmons and Lunn, 2022). The latest version of the radon risk map for Ireland, incorporating these features, is presented in Figure 1.1.

**FIGURE 1.1 RADON RISK MAP FOR IRELAND**



*Source:* https://gis.epa.ie/EPAMaps/Radon?&lid=EPA:RadonRiskMapofIreland.

In essence, the policy problem being addressed in this case is the threat to public health from residential exposure to radon gas. Markets may not be capable of addressing this problem adequately without regulation due to several apparent market failures:

- While information campaigns are used actively, not all members of the public are familiar with the risks of radon exposure (Timmons and Lunn, 2022; Vogeltanz-Holm and Schwartz, 2018);
- Some of those who are aware of it may not respond to the risk appropriately; research suggests that not everyone made aware of the general risk is amenable to testing for their specific risk level or to remediate their dwelling if testing shows a significant problem (Denman et al., 2005; Dowdall et al., 2016; WHO, 2009); and
- There may also be a principal-agent problem among those renting dwellings, whereby they are unable to remediate their dwellings even if they are aware of the problem.

If not all residents or investors take adequate account of radon risk when purchasing a newly built dwelling, builders and developers will not have efficient incentives to include radon protection measures without a regulatory intervention to require them.

## 1.4 IDENTIFICATION AND DESCRIPTION OF POLICY OPTIONS

Most radon prevention strategies in new build homes attempt to limit soil gas infiltration due to air pressure differences between the soil and the indoor occupied space, using methods such as active soil depressurisation, sealing surfaces, the installation of membranes, and ventilation of occupied and unoccupied spaces (WHO, 2009). One of the most common prevention methods for new buildings is the installation of a radon-proof membrane across the foundation, which has to be airtight and continuous (Jiránek and Kačmaříková, 2019; Khan et al., 2019; Ruvira et al., 2022). A systematic review of radon prevention and mitigation measures found that other radon mitigation techniques such as balanced heat recovery ventilation, active and passive indoor and underfloor ventilation, house pressurisation, simple sealing, and radon wells had variable levels of success in reducing radon concentrations (Khan et al., 2019). In this report, we focus on the installation of membranes as a preventive measure in new build homes in Ireland.

### 1.4.1 Baseline (status quo) option

Technical Guidance Document C (TGD-C) (Site Preparation and Resistance to Moisture) of the Building Regulations details the requirements for radon protection measures in new homes in Ireland. In high radon areas, the requirement is that:

> *a fully sealed membrane of low permeability over the entire footprint of the building and a potential means of extracting radon from the substructure such as a standby radon sump or sumps with connecting pipework or other appropriate certified systems should be provided.*

In non-high radon areas:

> *the building should be provided with a potential means of extracting radon from the substructure should that prove necessary after construction… the provision of a standby radon sump or sumps with connecting pipework or other appropriate certified system should be adequate* (Department of Housing, Local Government and Heritage, 1997).

TGD-C is updated periodically, with the last amendment occurring in 2020.[5]

To summarise, the current TGD-C requires the installation of a radon membrane and standby sump in high radon areas. In non-high radon areas, a standby sump is required. In addition, a damp-proof membrane is required in lieu of a radon membrane in non-high radon areas (Department of Housing, Local Government and Heritage, 1997).[6]

### 1.4.2 Policy options

The National Radon Control Strategy is the radon control strategy developed by an inter-agency group set up by the Irish Government in order to co-ordinate the policy response to reducing the health risks derived from exposure to radon. One of the actions of the strategy is to:

> *make recommendations to the Department of Housing, Planning and Local Government*[7] *on the amendment and strengthening of technical guidance on radon prevention in new buildings* (EPA, 2019).

In order to inform the planned revision of TGD-C, the EPA and Department of Housing, Local Government and Heritage (DHLGH) have defined three radon protection options to consider for new build homes, as follows:

1. A requirement for sealed radon membranes in all areas, including in those parts of the country not designated as high radon areas (option 1);

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[5] Amendments were last made to the guidance document in 2020: https://www.gov.ie/en/publication/1aa81-technical-guidance-document-c-site-preparation-and-resistance-to-moisture/.

[6] The definition of a high radon area in the current Building Regulations is based on the pre-May 2022 radon risk map, which used a 10km grid resolution to divide the country into radon risk zones.

[7] Now the Department of Housing, Local Government and Heritage (DHLGH).

2. A requirement to seal damp-proof membranes in non-high radon areas (option 2).
3. A requirement for sealed damp-proof membranes in all areas (option 3).

The baseline (status quo) requirement is sealed radon membranes in high radon areas, and unsealed damp-proof membranes in non-high radon areas.[8] The three options therefore vary both the population covered and/or the type of membrane. Further details on the technical specifications of each option,[9] which are then used as a basis for assessing costs and benefits, are provided in the Appendix. The following table (Table 1.1) summarises how the alternative policy options (options 1 – 3) differ from the 'status quo' or baseline option. It is assumed that all other requirements in the Building Regulations (e.g. the installation of a standby radon sump) are retained as detailed in TGD-C.

## TABLE 1.1 DESCRIPTION OF BASELINE AND POLICY OPTIONS

| | Baseline | Option 1 | Option 2 | Option 3 |
|---|---|---|---|---|
| **Description** | Sealed radon membrane in high radon areas (HRAs), and unsealed damp-proof membrane in non-high radon areas (non-HRAs) | Sealed radon membrane in all areas | Sealed damp-proof membrane in non-HRAs | Sealed damp-proof membrane in all areas |
| **Difference to baseline** | - | Extension of radon membrane to non-HRAs | For non-HRAs, requirement for damp-proof membrane to be sealed; requirement unchanged for HRAs | For non-HRAs, requirement for damp-proof membrane to be sealed;<br>for HRAs, replacement of a radon membrane with a sealed damp-proof membrane |

*Source:* Adapted from Department of Housing, Local Government and Heritage (1997) by the authors.

## 1.5 COST EFFECTIVENESS AND COST UTILITY ANALYSIS

In this report, we apply techniques used in the evaluation of health interventions to analyse the costs, benefits and other impacts for each option. Cost-effectiveness analysis (CEA) or cost-utility analysis (CUA) have generally been the preferred methods of economic evaluation of health interventions (Health Information and Quality Authority, 2019).[10] In a CEA, outcomes are expressed in terms of life years

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[8] We assume that the requirements for damp-proof membranes as currently specified in TGD-C do not achieve an airtight seal. Sections 2.12 and 2.13 of TGD-C set out the requirements for sealing and installation of radon membranes, while 3.1.5 sets out the requirements for sealing of damp-proof membranes. The requirements for radon membranes are stricter, requiring joints and service penetrations to be adequately sealed to achieve an airtight seal.

[9] See Table 3 of TGD-C for the detailed specifications of radon membranes required in Ireland.

[10] Cost benefit analysis (CBA) is rarely used due to the difficulty in expressing benefits of health interventions in monetary terms (Health Information and Quality Authority, 2019).

gained (or other relevant outcome if the intervention does not add life years), while in a CUA, the outcomes expressed in terms of quality-adjusted life years (QALYs). A QALY is a year of life adjusted for its quality, value or utility. One year in full health is given the value of 1 QALY; the same period in moderate pain, for example, might be given a value of 0.7 QALY. The QALY aims to incorporate quality and quantity of life in one measure (Health Information and Quality Authority, 2019; Svensson et al., 2018; WHO, 2009). The advantage of using CUA to evaluate health interventions or programmes is that the results can be compared with the alternative proposals and other health interventions (Health Information and Quality Authority, 2019).

In our model (described in greater detail in Chapter 2), we calculate the cost effectiveness of the three policy options specified above against the baseline (status quo) option. Cost effectiveness is calculated as the ratio of net change in cost to net change in outcome (the incremental cost effectiveness ratio, or ICER) (Gray et al., 2009; Health Information and Quality Authority, 2019). Chapter 2 details how costs and benefits are calculated for each option. The outcomes (lung cancer deaths averted) for each policy option are expressed in terms of life-years gained and QALYs gained:

$$ICER = \frac{(cost\ A\ - cost\ B)}{(outcome\ A\ - outcome\ B)}$$

The larger the ICER, the less cost effective the intervention. Historically, in Ireland, the threshold value for assessing cost-effectiveness has varied between €20,000 and €45,000 per QALY, although reimbursement below these levels was not guaranteed, and technologies above these thresholds have been adopted (Health Information and Quality Authority, 2019). Although HIQA guidelines propose taking a perspective from the view of the public health and social care system in Ireland, this report takes a broader societal perspective, i.e. incorporating costs and benefits that fall outside of the public health and social care system (such as material and installation costs of membranes which are borne by developers and builders).

## 1.6 PREVIOUS LITERATURE

There is a large body of literature assessing the effectiveness of different radon prevention and remediation measures in new and existing homes, but far fewer formal cost effectiveness analyses. One of the most comprehensive CUA studies was carried out in England and Wales by Gray et al. (2009). Gray et al. (2009) found that the policy requiring basic measures to prevent radon in new homes in selected areas (i.e. a sealed membrane in areas in which 3 per cent of homes are above the action level of 200 Bq/m$^3$) was highly cost effective (cost per QALY of £7,953), and such measures would remain cost effective if extended to the entire UK, with a cost per QALY gained of £11,400. Focusing on new builds in high radon areas (i.e. where

10 per cent of homes are above the action level), a requirement for radon to be measured in such houses after construction and occupation, and the installation of active measures, such as an electric fan, would result in a cost per QALY gained of £53,500.[11] In an extended analysis, the Health Protection Agency (2009) found that increasing the effectiveness of the membrane by 10 percentage points (from 50 to 60 per cent effectiveness) with an increase in costs from £100 to £150 was still cost-effective if applied to all new builds in England and Wales (i.e. below the UK cost-per-QALY threshold of £20,000). The same was true if effectiveness of the membrane was increased by 20 percentage points and costs increased from £100 to £200 for all new builds.

Coskeran et al. (2009) evaluated the cost effectiveness of four alternative strategies for radon protection in new build homes in England. They found that the central estimates of cost-effectiveness range from £2,870 per QALY gained for the most cost-effective of the alternative regimes (where no membranes are required during construction, but post-construction testing and remediation is required) to £6,182 for the current regime.[12] The authors note that these results suggest a case for introducing regulations for mandatory testing. In particular:

> *tests would identify where radon-proof membranes had failed and would mean that households would not face elevated risks to health, despite measures to protect against radon apparently having been taken.*

However, they also note that given the reluctance of householders to remediate in response to high radon readings, the current regime has the advantage of not relying on householder action.

Rather than carrying out a CUA of specific prevention measures, Gaskin et al. (2018b) conducted a CUA of two hypothetical radon prevention strategies in new build homes in Canada that would reduce indoor radon concentrations by 50 per cent and 85 per cent. The intervention with the 50 per cent reduction was considered broadly equivalent to the installation of passive preventive radon measures such as a radon protective membrane and sealing joints and cracks in the

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[11] The poor cost effectiveness occurs because basic preventive measures will already have halved radon levels, thereby reducing the number of homes with measurements above any particular action level and so increasing the cost of detecting them. The cost of fitting large numbers of sumps and pipework to all homes in the area, plus the high lifetime costs of running and maintaining active measures such as electric fans when required, also adversely affect cost effectiveness. The study also examined radon mitigation measures in existing homes in areas where 5 per cent of homes are above the action level, and found resulting cost per discounted QALY gained was £36,829. The authors note that this was above the maximum value that is typically considered good value for money when assessing alternative ways of improving health outcomes.

[12] The standard at the time of the study was to install a membrane during construction, and to install a sump in areas where more than 10 per cent of properties are above the radon action level of 200 bq/m$^3$, but with no post-installation radon testing.

floor and foundations, while the 85 per cent intervention was considered equivalent to the installation of an active (fan-powered) depressurisation. They found that a reduction in residential radon by 50 per cent could prevent 681 annual radon-attributable lung cancer deaths, associated with a period gain of 15,445 QALYs; and a reduction by 85 per cent could prevent 1,263 annual radon-attributable lung cancer deaths, associated with a period gain of 26,336 QALYs. Adopting a similar approach, Svensson et al. (2018) evaluated the cost-effectiveness of implementing radon protection and remediation measures in new and existing homes in Sweden to reach the WHO reference levels of 100 Bq/m$^3$ (from the current reference level in Sweden of 200 Bq/m$^3$). For new homes, the cost per QALY of reducing indoor radon levels to the lower level of 100 Bq/m$^3$ was estimated to be €11,061 (€39,174) if a full societal perspective[13] was adopted.

Gaskin et al. (2021) carried out a CUA of a recent recommendation to install a more radon resistant foundation barrier for new and existing housing in 2016, for each province and territory in Canada. This radon intervention in new housing was cost effective in all but one region, ranging from $18,075/QALY for the Yukon to $58,454/QALY for British Columbia. Also in Canada, Létourneau et al. (1992) carried out a CEA of radon reduction strategies, including the installation of sub-slab suction devices in new homes. As radon levels in Canadian homes are low, all options considered were very expensive, with the option of testing and remediation at point of sale considered the most cost-effective.

Pollard and Fenton (2014), for Ireland, carried out a CUA focusing on three strategies: prevention incorporated in new homes at the time of construction, remediation (where a standby sump was not present in the house), and remediation by activation of a standby sump. For each intervention, the cost effectiveness was modelled for two scenarios: the first assuming the intervention was targeted at the whole country and the second that the intervention was targeted at high radon areas (HRAs) only. Of all the scenarios considered, radon prevention in new houses was the most cost effective, with a cost per QALY of €8,774 for HRAs, and €12,524 for the whole country.

Studies that have focused on radon remediation measures in existing homes include those by Denman et al., 2005; Ford et al., 1999; Haucke, 2010; Kennedy et al., 1999; Kennedy and Gray, 2000; 2001; and Petersen and Larsen, 2006.

While not CEA/CUAs, a number of Irish and international studies have assessed the effectiveness of radon membranes by conducting measurements of new homes

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[13] In this study, the societal perspective accounted for the extra healthcare costs associated with additional life years saved due to radon protection measures.

before and after the introduction of relevant building standards. For example, Dowdall et al. (2017) analysed the average indoor radon concentration of houses built pre- and post-1998 (when the requirements in Technical Guidance Document C were first introduced). They found that the mean radon concentration in homes built after 1998 was 64 Bq/m$^3$, while it was 86 Bq/m$^3$ in homes built prior to 1998, a statistically significant reduction of 26 per cent. Based on a much smaller sample, Long et al. (2013) reported a reduction in the mean radon concentration of approximately 55 per cent in local authority homes built in HRAs in County Cork since 1998, relative to those built before that date.

Denman et al. (2018) assessed the effectiveness of the current UK building standards for radon prevention in new build homes.[14] Based on a cross-sectional investigation of 26 new housing developments in high-radon areas in Northamptonshire, they found that while radon-proof membranes in general ensured that radon concentrations in new homes constructed in accordance with the Building Regulations in Radon Affected Areas (RAAs) were satisfactorily low, there was a very small statistical probability that levels in a small number of homes were close to or above the action level, particularly in areas of high radon potential. They therefore recommended that the Public Health England (PHE) recommendation for testing in the first year of occupation be adopted as a legal requirement.

Hodgson et al. (2019) assessed the effectiveness of 'basic' and 'full' radon protection measures in new homes in England and Wales by comparing indoor radon measurements for a sample of homes based on date of construction and location in a radon risk area. They found that the geometric mean of radon concentration in homes with radon protection built since 2001 was 48 per cent lower than the mean concentration in homes built before 1993 without radon protection. Comparing the same group of protected homes with unprotected homes built in the period 1977-1993 showed a slightly lower but similar reduction (42 per cent) in mean radon concentration.

In Norway, results from two national surveys of radon in newly built homes, performed in 2008 and 2016, were used to investigate the effect of the 2010 building regulations[15] introducing limit values on radon and requirements for radon prevention measures upon construction of new buildings (Finne et al., 2019). The

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[14] Current regulations require a suitable radon-proof membrane, of 1200 Gauge (300 µm thickness) polythene or equivalent, to be used as combined radon-protection and damp-course in new-build houses in RAAs. In addition, in areas of higher radon potential, where over 10 per cent of existing houses have been found with raised radon levels, a sump is required to enable future implementation of pumped extraction of gas from below the ground floor if subsequently indicated by post-construction testing of indoor radon levels (Denman et al., 2018).

[15] The specific radon prevention measure is a radon membrane over the entire base area of the building in combination with a passive radon sump system. The passive sump may be activated with an electric fan when indoor radon concentration exceeds the action level. The action level is 100 Bq/m$^3$ and the upper limit value is 200 Bq/m$^3$.

analysis found that while overall there was a significant reduction in radon concentrations over time, the effects differed by building type. A statistically significant reduction was found for detached houses where the average radon concentration was almost halved from 76 to 40 Bq/m$^3$. For terraced and semi-detached homes, the reduction (from 44 to 29 Bq/m$^3$) was not statistically significant (while for multifamily houses, it was not possible to draw a conclusion due to insufficient number of measurements). A recent systematic review of 66 studies of radon protection measure effectiveness by Khan et al. (2019) concluded that regardless of the prevention method used, errors in installation or damage during construction can result in ineffective protection. They noted that training of radon mitigation personnel and builders as well as post-construction and post-remediation testing is required.

## 1.7 STRUCTURE OF THE REPORT

In Chapter 2, we provide an outline of the methods and model we use for assessing costs, benefits and other impacts of each policy option, with the Appendices providing further details on the parameters required for input into the model. Chapter 3 describes the main results and sensitivity analyses, while Chapter 4 discusses the findings and concludes.

# CHAPTER 2

# Methods for analysing costs, benefits and other impacts for each option

## 2.1 INTRODUCTION

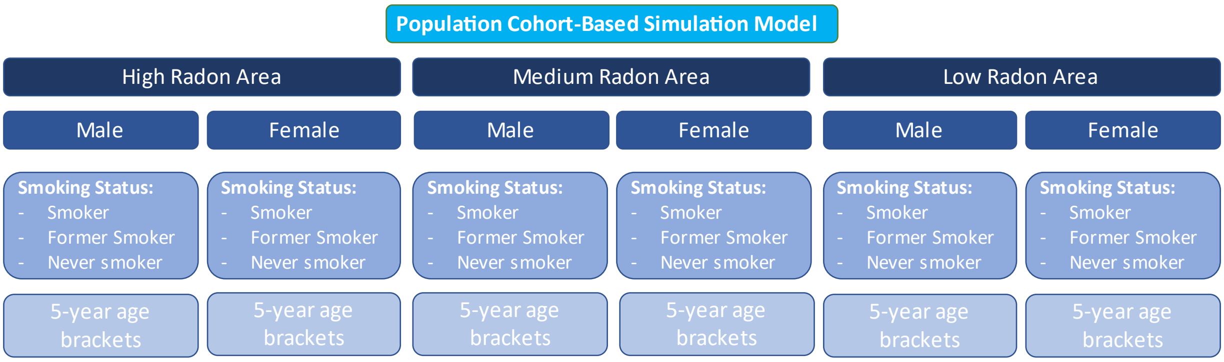
Kennedy and Gray (2001) set out a framework for cost effectiveness analysis (which is used in their study to evaluate the cost effectiveness of radon remediation measures in the UK). They note the importance of defining the objective (e.g. reducing lung cancer cases), perspective (e.g. societal), choice of comparator(s), time horizon (i.e. the period over which costs and benefits are expected to occur), discount rate, and how uncertainty will be considered. See also Health Information and Quality Authority (2019) and WHO (2009). In this chapter we use this framework to describe the cost effectiveness model we employ to assess the costs and benefits of the three alternative radon protection measures outlined in Section 1.4. The appendices provide further detail on the data and sources for the various model parameters. Appendix A.1 details the data sources and assumptions for static model parameters (e.g. discount rate, lung cancer risk per Bq/m$^3$, etc.). Appendix A.2 outlines how the average radon concentration in each radon risk area is calculated. Appendix A.3 details the technical specifications for the various policy options considered. Appendices A.4-A.6 outline how the various dynamic parameters are derived, in relation to demography and house building estimates (Appendix A.4), smoking prevalence (Appendix A.5) and future healthcare costs (Appendix A.6).

## 2.2 QUANTITATIVE ANALYSIS OF COSTS AND BENEFITS

### 2.2.1 Methods

As far as possible, we try to take a societal cost-benefit perspective rather than focusing more narrowly on the costs and benefits to the Exchequer or the healthcare system. This seems appropriate as most costs of these measures fall on developers and purchasers of housing rather than on healthcare providers or the government. Where possible, we monetise cost and benefits. This is practicable for some key sources of cost variation across options, particularly material and installation costs. Some benefits can also be monetised; for example, healthcare cost savings from avoided lung cancer cases. However, the main source of benefits is from additional life years obtained when lung cancer incidence is reduced. We use a cost effectiveness and cost utility perspective for quantifying these benefits, showing how costs of the various options relate to the life years or quality-adjusted life years that are saved by the measures (see also Section 1.5). To analyse quantifiable costs and benefits, we employ a cohort-based simulation model (with the population disaggregated by five-year age band, sex, smoking status and radon risk area).[16] An illustration of the cohort-based simulation model is provided in Figure 2.1. For each cell, relevant costs and benefits are calculated.

FIGURE 2.1 ILLUSTRATION OF COHORT-BASED SIMULATION MODEL



*Source:* Authors' analysis.

### 2.2.2 Costs

When estimating costs, the cohort-based simulation model relies on ESRI projections of the numbers of new residences that will be constructed in each of three radon risk areas for 20 years from 2024 (see Appendix A.4). For each annual cohort of projected newly-built residences, the total cost associated with each regulatory option (including the baseline) is calculated by multiplying the projected number of residences built by the average expected material and installation[17] cost of radon measures under that option (see Appendix A.3 for material and installation costs per square metre). The cost of radon prevention measures per new build is based on an assumed cost per square metre times the weighted average ground floor areas of new build dwellings. Differing costs between residences with higher or lower complexity in floor plans is taken into account when averaging costs from different residence types (see Appendix A.1 for how ground floor areas, housing types, and complexity shares, for new build homes are estimated). Figure 2.2 visually demonstrates how the cost component of the model is constructed.

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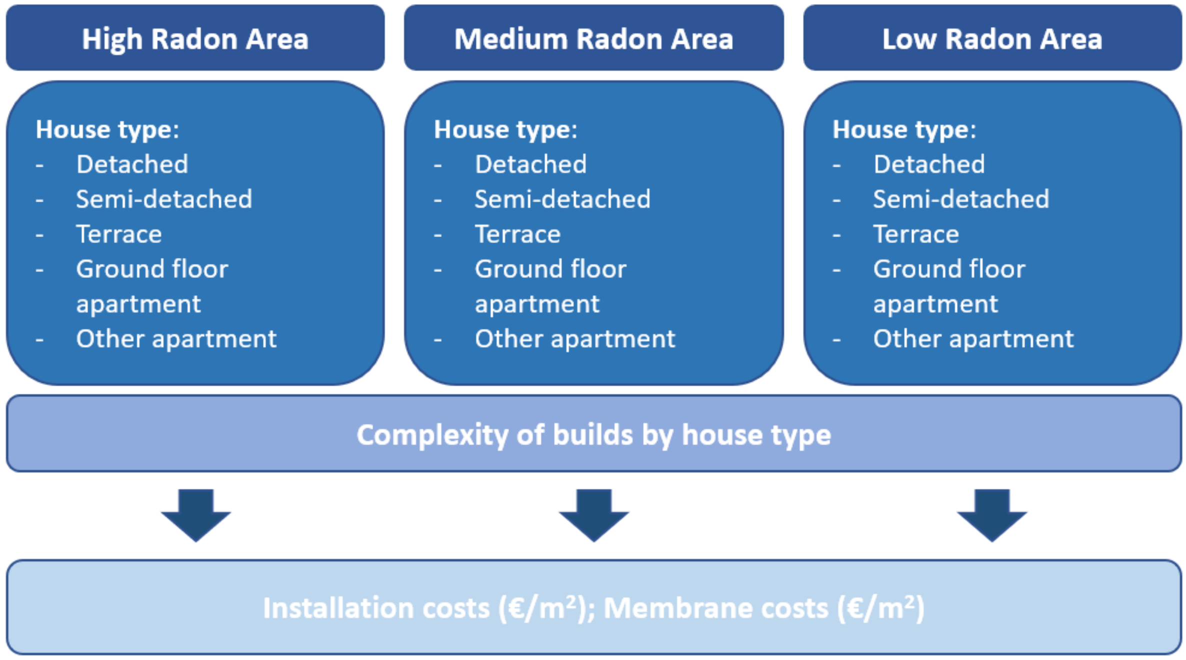
[16] We use the new EPA radon risk map (see Figure 1.1 and Section 1.3) to disaggregate the population into radon risk areas. See also Appendix A.1.

[17] There is also scope to allow for differences in administrative costs (e.g. inspection costs) among the options, but we were not able to identify suitable data to incorporate administrative costs into our model.

**FIGURE 2.2 ILLUSTRATION OF COHORT-BASED SIMULATION MODEL: COSTS**



*Source:* Authors' analysis.

Having arrived at material and installation cost estimates for each building type in each radon zone in each year, we express the total cost over the 20 years in present value terms, using the discount factor (4 per cent) currently recommended by Ireland's Department of Public Expenditure and Reform for public expenditure evaluations (Department of Public Expenditure and Reform, 2019).[18] The analysis is conducted in real terms, apart from some components of healthcare costs that are expected to have higher inflation rates (see Appendix A.6).

### 2.2.3 Benefits

Projected benefits arise to the extent that each regulatory option prevents lung cancer cases that would otherwise have occurred. To model these benefits, we again focus on the annual cohort of residences expected to be constructed over the 20-year period mentioned above. We assume that an average of 2.7 persons live in each residence (regardless of housing type)[19] (see Appendix A.1), and that the population is split into radon risk areas and age bands (applying a common national projection of the share of population in each age band by year to the groups in the three radon risk areas) (see Appendix A.4). We further divide the sample in each radon risk area and age category into three smoking status groups (current smokers, past smokers and never smokers), using a model that applies scenarios

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[18] A discount rate of 4 per cent is also recommended for the assessment of health interventions (Health Information and Quality Authority, 2019).

[19] Although there are likely to be differences in household size across housing types (bungalows, semi-detached, apartments), we impose this simplifying assumption in the model.

for how smoking prevalence may be expected to change over time (see Appendix A.5).

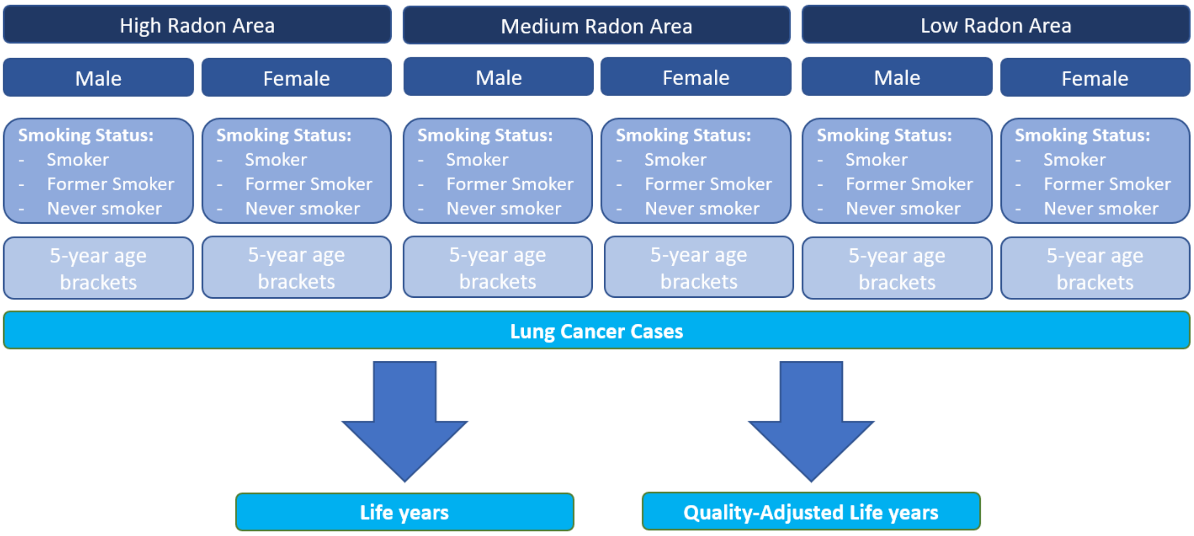
The ‘treated’ population in each demographic cell (defined by five-year age band, sex, smoking status and radon risk area) grows over time as more residences are built. We follow each cohort of additions for 25 years, so benefits relating to the people living in residences built during those years arise from 2024-2067.

The number of lung cancer cases projected annually in each cell (age band/sex/ smoking status/radon risk area) is projected using a formula based on the affected population, the age-sex-specific lung cancer risk for non-smokers, the relative risk of lung cancer for current and former smokers, and the relative risk of lung cancer per Bq/m$^3$ of radon exposure (see Appendix A.1 for further details).

For each age band, the number of life years lost per cancer case is calculated as a function of the mortality rate and average life expectancy (drawn from the CSO Life Tables). The life years are also adjusted to allow for variations in the Quality of Life Expectancy (QALE) of males and females at different ages (see Appendix A.1 for parameter values and data sources). This yields an estimate of the Quality-Adjusted Life Years (QALYs) saved under each regulatory option compared to the baseline. Both savings in life years and QALYs are discounted using the same discount factor as discussed in the cost part of the analysis.

Some further benefits and costs arise due to avoided lung cancer cases. First, those being treated for cancer need a range of acute healthcare services. We obtain estimates of the numbers of inpatient and day case hospital discharges associated with the average case by dividing the number of discharges reporting a lung cancer diagnosis in 2019 by the incidence of lung cancer in that year. This relies on an assumption that cancer incidence bears a broadly constant relationship to prevalence over recent years. Projected numbers of future discharges of each type can then be multiplied by the average cost of each type of services (drawn from administrative data). Similar calculations are done for general practitioner (GP) visits and outpatient appointments, except that in the absence of Irish activity data we use estimates drawn from academic literature. Finally, we include a rough estimate of social care and palliative care costs by calculating the ratio of these costs to healthcare costs from UK research and applying it to the base year Irish healthcare cost figures described above (see Appendix A.1). Acute hospital care costs have tended to grow faster than general inflation in the past, so we apply scenarios to adjust for acute care components of cost for the expected excess of healthcare wage and non-wage inflation over general inflation. Figure 2.3 illustrates how the benefit components of the model are calculated and incorporated.

## FIGURE 2.3 ILLUSTRATION OF COHORT-BASED SIMULATION MODEL: BENEFITS



*Source:* Authors' analysis.

## 2.3 UNCERTAINTY

Cost-effectiveness results are likely to be subject to a considerable amount of uncertainty, for example due to lack of precision in input parameters. One way of dealing with this is to report the results of one-way sensitivity analyses, in which key input variables are varied across a plausible range to assess their impact on the results, holding all other variables constant. Section 3.3 details the results of the sensitivity analyses conducted for this report, in which we vary assumptions relating to population growth, healthcare cost inflation, future smoking prevalence etc. Clearly, many other uncertainties could be examined, such as the possible existence of some threshold or non-linear exposure-response relationship, or future changes in household size, life expectancy, and costs and benefits of preventive actions (WHO, 2009). However, appropriate data are often inadequate or not available. We also conduct a number of scenario sensitivity analyses, where we vary key input parameters together (e.g. a 'high pressure' scenario in which projected population growth is higher, housing demand is higher, etc.).

# CHAPTER 3

# Results

## 3.1 INTRODUCTION

In this chapter, we discuss the main results from the cost effectiveness analyses of the three policy options, relative to the baseline (status quo) situation. Results are presented in the form of costs per life year gained and cost per QALY gained. This enables comparison of the cost effectiveness of the three radon protection policy options with each other and with other public health interventions. Section 3.2 describes the main results while Section 3.3 describes the results of a number of sensitivity analyses that were undertaken, in which key parameters in relation to future housing demand, population growth, future smoking prevalence, healthcare cost inflation, material and installation costs, time spent at home, and membrane radon reduction benefits are varied.

## 3.2 MAIN RESULTS

Table 3.1 sets out the costs per life year gained and QALY for each of the three proposed policy options, compared to the baseline (status quo) option. Costs relate to material and installation costs (see Figure 2.2), with benefits (lung cancer deaths averted) expressed in terms of life years gained and QALYs gained (see Figure 2.3). All costs and benefits are discounted to present values using appropriate discount rates. The appendices provide further details on the key parameters used in the model. These results are based on a number of key assumptions for time-varying parameters as outlined below:

- Housing demand projections are taken from the ‘baseline’ scenario of Bergin and Garcia Rodriguez (2020), which predicts housing demand of approximately 28,000 per annum (see also Appendix A.4);

- Population size and age distribution projections are based on the ‘central population’ scenario of Keegan et al. (2022) (see also Appendix A.4);

- Assumptions about future smoking prevalence are based on the national anti-smoking policy targets of a 1 percentage point decline per annum (see also Appendix A.5);

- Unit costs of healthcare grow according to the ‘Recovery’ scenario outlined in Keegan et al. (2020) (see also Appendix A.6).

The results in Table 3.1 show that relative to the baseline (status quo) option, policy option 1 is the most expensive in terms of costs per QALY, at €31,710 per QALY. Option 3 is cost-saving, i.e. it results in a cost saving per life year and QALY relative to the baseline (status quo) option. This arises because the model assumes the same benefit (i.e. reduction in radon concentration) for radon membranes and sealed damp-proof membranes, while costs are higher for radon membranes. As a result, requiring all areas of the country to be fitted with a sealed damp-proof membrane is more cost effective than the current situation whereby those living in HRAs are required to have a radon membrane, while those in non-HRAs are assumed to have an unsealed damp-proof membrane only.

While there is no official cost per QALY threshold in Ireland, in general, interventions with a cost per QALY below €20,000-€45,000 have been considered cost effective in previous evaluations. However, reimbursement below these levels was not guaranteed, and technologies above these thresholds have been adopted (Health Information and Quality Authority, 2019). Nonetheless, the range provides a useful benchmark for assessing the policy options considered in this study. Using this range, all three options would be considered cost effective as they fall below the thresholds above. In addition, option 3 is in fact cost-saving, which is indicated by the negative values in Table 3.1.[20]

TABLE 3.1 COSTS PER LIFE YEAR/QALY OF PROPOSED POLICY OPTIONS

| Policy Option | Cost per Life Year/QALY |
|---|---|
| **Baseline (status quo)** | - |
| **Policy Option 1 (Sealed radon membrane in all areas)** | Cost per life year: €23,640<br>Cost per QALY: €31,710 |
| **Policy Option 2 (sealed damp-proof membrane in non-HRAs)** | Cost per life year: €596<br>Cost per QALY: €799 |
| **Policy Option 3 (sealed damp-proof membrane in all areas)** | Cost per life year: -€10,885<br>Cost per QALY: -€14,600 |

*Source:* Authors' analysis.

## 3.3 SENSITIVITY ANALYSES

Given the range of input parameters used in this model (see Appendices), there are multiple sensitivity analyses that can be carried out. However, in many cases, there is a lack of data on alternative parameter values (e.g. projections of new building types across radon risk areas). In this section, we describe the results of analyses where we vary a number of key input parameters (those that are time-varying, and those that are static) in order to illustrate the sensitivity of the results in Table 3.1 to alternative assumptions. We also undertake a number of sensitivity analyses that vary a number of key input parameters at the same time, rather than one-by-one.

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[20] To put these results in context, a CUA of smoking cessation strategies in Ireland (relative to unaided quitting) found that all three strategies (e-cigarettes, Varenicline, and Varenicline combined with nicotine replacement therapy) were cost-effective, with respective costs per QALY of €5,249, €6,584 and €7,025 (Health Information and Quality Authority, 2017).

In the first instance, we vary some key time-varying parameters. The sensitivity analyses that are conducted are:

- Housing demand projections are varied by using the ‘high international migration’ scenario of Bergin and Garcia Rodriguez (2020), which predicts housing demand of approximately 33,000 per annum (see also Appendix A.4);
- Population size and age distribution projections are varied to reflect the ‘high population’ scenario of Keegan et al. (2022) (see also Appendix A.4);
- Assumptions about future smoking prevalence are varied to assume a slower rate of decline in smoking prevalence of 0.5 percentage points decline per annum (see also Appendix A.5);
- Unit costs of healthcare grow at a slower pace, i.e. the ‘Delayed Recovery’ scenario outlined in Keegan et al. (2020) (see also Appendix A.6).

The results of these sensitivity analyses are outlined in Table 3.2. The results show that varying these key assumptions about time-varying parameters does not change the relative outcomes of the main analysis. Option 3 is still the most cost effective (and is always cost-saving), while option 1 is relatively less cost effective, but still cost effective under the threshold of costs per QALY of €20,000 – €45,000 that is typically used in Irish health technology evaluations. Option 2 becomes cost-saving when a lower rate of decline in smoking prevalence over time is assumed, reflecting the higher absolute risk of lung cancer among smokers exposed to high indoor radon levels.

TABLE 3.2 COSTS PER LIFE YEAR/QALY OF PROPOSED POLICY OPTIONS (SENSITIVITY ANALYSES, SELECTED TIME-VARYING PARAMETERS)

| Policy Option | Higher Housing Demand | Higher Population Growth | Lower Rate of Decline in Smoking | Lower Rate of Healthcare Cost Inflation |
|---|---|---|---|---|
| **Baseline (status quo)** | - | - | - | - |
| **Policy Option 1 (Sealed radon membrane in all areas)** | Cost per life year:<br>€23,737<br>Cost per QALY:<br>€31,842 | Cost per life year:<br>€24,937<br>Cost per QALY:<br>€33,457 | Cost per life year:<br>€19,950<br>Cost per QALY:<br>€26,755 | Cost per life year:<br>€23,766<br>Cost per QALY:<br>€31,879 |
| **Policy Option 2 (sealed damp-proof membrane in non-HRAs)** | Cost per life year:<br>€600<br>Cost per QALY:<br>€804 | Cost per life year:<br>€849<br>Cost per QALY:<br>€1,139 | Cost per life year:<br>-€146<br>Cost per QALY:<br>-€196 | Cost per life year:<br>€722<br>Cost per QALY:<br>€968 |
| **Policy Option 3 (sealed damp-proof membrane in all areas)** | Cost per life year:<br>-€10,885<br>Cost per QALY:<br>-€14,466 | Cost per life year:<br>-€11,152<br>Cost per QALY:<br>-€14,962 | Cost per life year:<br>-€10,158<br>Cost per QALY:<br>-€13,624 | Cost per life year:<br>-€10,759<br>Cost per QALY:<br>-€14,431 |

*Source:* Authors’ analysis.

Second, we vary some key static parameters. The sensitivity analyses that are conducted are:

- Higher material and installation costs (i.e. assuming that all new builds are 'complex' builds; see also Appendices A.1 and A.3);
- Lower material and installation costs (i.e. assuming that all new builds are 'simple' builds; see also Appendices A.1 and A.3);
- Assumptions about time spent at home are varied to assume a greater proportion of time spent at home due to hybrid working post-pandemic (see also Appendix A.2);
- The assumption of a 50 per cent reduction in radon concentrations for both sealed radon and damp-proof membranes is varied to assume a lower radon reduction benefit for sealed damp-proof membranes (30 per cent) (see Appendix A.3).[21]

The results of these sensitivity analyses are outlined in Table 3.3. The results show that, with the exception of the last sensitivity analysis, varying these key assumptions about static parameters does not change the relative outcomes of the main analysis. However, the cost effectiveness of the third policy option is highly sensitive to an alternative assumption about the protection offered by sealed radon vs. damp-proof membranes (although the data underlying this assumption are illustrative rather than evidence-based). In the main analysis, we assume that a sealed damp-proof membrane offers the same protection against radon as a sealed radon membrane (an average reduction of 50 per cent in radon concentration) (see Table A.2). This reflects our assumption that the quality of installation (i.e. achieving an airtight seal) is the crucial parameter, rather than the type of membrane per se. In the sensitivity analysis, we assume that a sealed damp-proof membrane is not as effective as a sealed radon membrane in terms of radon protection (i.e. that it can result in a 30 per cent reduction in indoor radon concentrations, rather than 50 per cent). Under this alternative scenario, the cost per QALY of option 3 is now just below the maximum threshold for cost effectiveness used in Irish decisions about healthcare interventions. This arises because while sealed damp-proof membranes are cheaper per square metre (see Table A.3 in the Appendix), a lower benefit in terms of radon reduction, applied to the full population (including those in high radon areas), renders this option much less cost effective than if the benefit of a sealed damp-proof membrane is assumed to be the same as a sealed radon membrane.

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[21] However, it must be emphasised that this is an illustrative exercise, as there are no data to support the alternative assumption of a lower radon reduction benefit for sealed damp-proof membranes than for sealed radon membranes. See also Appendix A.3.

## TABLE 3.3 COSTS PER LIFE YEAR/QALY OF PROPOSED POLICY OPTIONS (SENSITIVITY ANALYSES, SELECTED STATIC PARAMETERS)

| Policy Option | Higher Material and Installation Costs | Lower Material and Installation Costs | Higher Time Spent at Home | Lower radon reduction benefit for sealed damp-proof membrane |
|---|---|---|---|---|
| **Baseline (status quo)** | - | - | - | - |
| **Policy Option 1 (Sealed radon membrane in all areas)** | Cost per life year: €27,250<br>Cost per QALY: €36,552 | Cost per life year: €21,850<br>Cost per QALY: €29,308 | Cost per life year: €20,724<br>Cost per QALY: €27,698 | Cost per life year: €23,640<br>Cost per QALY: €31,710 |
| **Policy Option 2 (sealed damp-proof membrane in non-HRAs)** | Cost per life year: €1,566<br>Cost per QALY: €2,100 | Cost per life year: €177<br>Cost per QALY: €238 | Cost per life year: €200<br>Cost per QALY: €268 | Cost per life year: €4,489<br>Cost per QALY: €6,021 |
| **Policy Option 3 (sealed damp-proof membrane in all areas)** | Cost per life year: -€11,230<br>Cost per QALY: -€15,064 | Cost per life year: -€10,620<br>Cost per QALY: -€14,246 | Cost per life year: -€10,024<br>Cost per QALY: -€13,398 | Cost per life year: €32,914<br>Cost per QALY: €44,155 |

*Source:* Authors' analysis.

Finally, we conduct a number of sensitivity analyses where we vary multiple input parameters at the same time. First, we model a 'high pressure' scenario where we assume higher population and housing demand, i.e.:

- Housing demand projections are varied by using the 'high international migration' scenario of Bergin and Garcia Rodriguez (2020), which predicts housing demand of approximately 33,000 per annum (see also Appendix A.4);
- Population size and age distribution projections are varied to reflect the 'high population' scenario of Keegan et al. (2022) (see also Appendix A.4).

In the second scenario ('very high pressure'), we add to the first scenario by also assuming that material and installation costs may be higher:

- Higher material and installation costs (i.e. assuming that all new builds are 'complex' builds (see also Appendices A.1 and A.3).

In the final scenario ('individual behaviour'), we focus on the parameters relating to individual behaviour, and assume a lower rate of smoking prevalence combined with increased time spent at home due to hybrid working:

- Assumptions about future smoking prevalence are varied to assume a slower rate of decline in smoking prevalence of 0.5 percentage points decline per annum (see also Appendix A.5);

- Assumptions about time spent at home are varied to assume a greater proportion of time spent at home due to hybrid working post-pandemic (see also Appendix A.2).

The results are presented in Table 3.4 and indicate no major change in the main conclusions from the analysis, i.e. all options would be considered cost-effective under current Irish thresholds for health technologies, with option 3 cost-saving. Reflecting the relatively higher benefits of radon protection measures in the context of a slower rate of decline in smoking prevalence (and consequently a greater number of projected lung cancer cases), and more hybrid working, option 2 also becomes cost-saving under the 'individual behaviour' scenario.

**TABLE 3.4 COSTS PER LIFE YEAR/QALY OF PROPOSED POLICY OPTIONS (SENSITIVITY ANALYSES, MULTIPLE PARAMETERS VARIED)**

| Policy Option | High Pressure | Very High Pressure | Individual Behaviour |
|---|---|---|---|
| **Baseline (status quo)** | - | - | - |
| **Policy Option 1 (Sealed radon membrane in all areas)** | Cost per life year: €25,051<br>Cost per QALY: €33,612 | Cost per life year: €28,842<br>Cost per QALY: €38,698 | Cost per life year: €17,439<br>Cost per QALY: €23,304 |
| **Policy Option 2 (sealed damp-proof membrane in non-HRAs)** | Cost per life year: €856<br>Cost per QALY: €1,148 | Cost per life year: €1,874<br>Cost per QALY: €2,515 | Cost per life year: -€460<br>Cost per QALY: -€615 |
| **Policy Option 3 (sealed damp-proof membrane in all areas)** | Cost per life year: -€11,048<br>Cost per QALY:-€14,824 | Cost per life year: -€11,394<br>Cost per QALY:-€15,288 | Cost per life year: -€9,377<br>Cost per QALY:-€12,531 |

*Source:* Authors' analysis.

# CHAPTER 4

# Summary and Discussion

## 4.1 SUMMARY

This evaluation of three alternative policy options for radon prevention in new build homes in Ireland found that all three options would be considered cost-effective under current threshold values for the evaluation of health interventions in Ireland, with one policy option (sealed damp-proof membranes in all areas) cost-saving. However, sensitivity analysis revealed that the cost effectiveness of the sealed damp-proof membrane in all areas option was highly sensitive to an alternative assumption about the protection offered by radon vs. damp-proof membranes (although the data underlying this assumption were illustrative rather than evidence-based). These results were generated using a population cohort simulation model that contrasted the costs (i.e. material and installation costs of the selected membranes, healthcare costs of lung cancer treatment, etc.) against the benefits of the different membranes in terms of lung cancer cases averted. A number of other sensitivity analyses that varied assumptions about key time-varying parameters (e.g. rate of population growth) and static parameters (e.g. material and installation costs) were also undertaken.

## 4.2 DISCUSSION

As with any cost effectiveness analysis, the results are dependent on the underlying assumptions that are made about the various parameters inputted into the model. Where possible, we adopted a broad societal perspective in assessing costs and benefits, but due to the absence of appropriate data it was not always possible to incorporate assumptions about potentially important costs and benefits. For example, the benefits associated with radon prevention measures may also include added productivity during the (working) life years of the individuals who do not develop lung cancer as a result of radon prevention measures, but we were not able to source data for this purpose. Similarly, it has been noted that those who do not develop lung cancer incur other healthcare costs during their added life years (Health Protection Agency, 2009), but once again, we were not able to source accurate data for this purpose. More generally, many of the parameters used in this model are based on data from other countries (e.g. on time spent at home). While every effort has been made to source data from Ireland, this was not possible and data from other countries had to be used instead.

The costs of the membranes examined in this study cover the material and installation costs only. Potentially important regulatory costs (e.g. post-construction inspection costs), as well as administrative costs on the industry given the increased spatial granularity of the new radon risk map (see Figure 1.1), are not considered due to a lack of data. In addition, during this study, discussions with industry suggested that some builders ‘over-comply’ with radon-related Building Regulations on a portion of sites. For example, a firm might install radon membranes on all of its sites (regardless of the radon risk area designation) to avail of economies of scale in purchasing materials or in training staff on a standardised installation process. To the extent this behaviour is widespread, requiring radon membranes or additional sealing work in one area might lead to some amount of voluntary compliance in other regions where it is not required. Health Protection Agency (2009) note that there may be other benefits to extending the requirement for a radon membrane to all areas of the country; a single consistent standard is more easily applied, and radon membranes would also prevent the entry of vapour and other gases from the ground.

Possible ‘overcompliance’ with current regulations also highlights the importance of the specification of the baseline option, as all three policy options are evaluated relative to the baseline option. If there is widespread ‘overcompliance’ with current regulations (i.e. builders are installing radon membranes in all areas, including non-HRAs), then the baseline option would be closer to policy option 1. Similarly, if there is more widespread use of airtight seals for damp-proof membranes at present, then the baseline option would be closer to option 2. However, we were not able to find data on how widespread ‘overcompliance’ might be. If data on the extent of ‘overcompliance’ with current requirements were available, the model could be adjusted to assess the sensitivity of the results to alternative assumptions about compliance.

A final, potentially significant, source of costs and benefits that we have not been able to quantify relates to the quality of installation and sealing of radon (and damp-proof) membranes. To some extent however, this variability is accounted for by the use of a common 50 per cent reduction in indoor radon concentration benefit for both radon and sealed damp-proof membranes. Consultation with industry representatives, as well as those involved in previous cost effectiveness analyses in the UK, stressed the importance of the quality of the installation of membranes (i.e. achieving an airtight seal), rather than the type of membrane per se, for protection against indoor radon. As noted also by Khan et al. (2019), where perfect installation should ensure a significantly lower radon level in a home, in practice errors in installation or damages during construction can result in ineffective protection. This warrants training of builders or site staff who install the required radon preventive measures, as well as the need for radon testing post-construction when the building is in use. More widespread inspection of sites during and after construction may also be required.[22]

In summary, while all alternative policy options would be considered cost-effective under current Irish thresholds for health technology assessment, the choice of alternative option is dependent on the extent to which the assumptions underlying these options (and the baseline 'status quo' option) are considered valid. For example, while option 3 is cost-saving (and therefore the most preferred option from the model), this result is highly sensitive to the assumption that sealed radon and sealed damp-proof membranes offer identical protection against radon. The choices facing policymakers must therefore take into account these sensitivities, as well as other behaviours that cannot, at present, be quantified in this analysis such as the degree of 'overcompliance' with current regulations.

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[22] See https://www.gov.ie/en/publication/3e711-building-control/ and Department of Housing, Planning, Community and Local Government (2016) for a description of the current requirements for inspection of compliance with Building Regulations.

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# APPENDICES

## A.1 STATIC PARAMETERS

### TABLE A.1 OVERVIEW OF STATIC PARAMETER VALUES

| Parameter | Values |
|---|---|
| **Radon risk area** | High: 35.1%<br>Medium: 37.0%<br>Low: 27.9% |
| **Average indoor radon concentration by radon risk area** | Baseline:<br>High: 122.1 Bq/m$^3$<br>Medium: 73.6 Bq/m$^3$<br>Low: 55.9 Bq/m$^3$<br>See also Appendix A.2 |
| **Share of new residential builds by type (Share of complex builds)** | Detached house: 42.6%<br>(Complexity share: 50%)<br>Semi-detached house: 28.2%<br>(Complexity share: 27%)<br>Terraced house: 17.0%<br>(Complexity share: 18%)<br>Ground floor apartment: 3.4%<br>(Complexity share: 1%)<br>Other apartment: 8.8%<br>(Complexity share: 3%) |
| **Ground floor area of new residential builds by type** | Detached house: 180m$^2$<br>Semi-detached house: 62m$^2$<br>Terraced house: 57m$^2$<br>Ground floor apartment: 81m$^2$<br>Other apartment: 83m$^2$ |
| **Average household size** | 2.7 |
| **Average time spent at home** | Age 0-24: 62.5%<br>Age 25-64: 60.8%<br>Age 65+: 81.3% |
| **Discount rate** | 4% |
| **Material and installation cost by policy option** | See Appendix A.3 |
| **Age-specific lung cancer risk per annum** | See below |
| **Reduction in average indoor radon concentration by option** | See Appendix A.3 |
| **Lung cancer risk per Bq/m$^3$** | 16% per 100Bq/m$^3$ |
| **Life expectancy by age and sex** | See below |
| **QALY weights by age and sex** | See below |
| **Acute (inpatient, day case and ED) utilisation per lung cancer case** | Inpatient: 8.9<br>Day case: 2.4<br>ED: 1.4 |
| **Acute (inpatient, day case and ED) cost of treating lung cancer case** | Inpatient: €4,985<br>Day case: €885<br>ED: €298 |
| **Non-acute (GP, outpatient, other) utilisation per lung cancer case** | GP: 21.8<br>Outpatient: 10.8<br>Other: see text below |
| **Non-acute (GP, outpatient, other) cost of treating lung cancer case** | GP: €1,088<br>Outpatient: €1,847<br>Other: €30,609 |

*Source:* Authors' analysis.

## RADON RISK AREA

We use the latest EPA radon risk map (see Figure 1.1[23] in Section 1.3) to calculate the share of residential properties being constructed in each radon risk zone. Radon risk zones denote high (>=10 per cent of residences at risk of indoor radon level above 200 Bq/m$^3$), medium (>=5 per cent) or low (<5 per cent) radon risk. Because projections of new residential construction are available only at county level (see below), we multiply predicted county-level new build numbers by a concordance matrix that maps them on radon risk zones in proportion to the mapping between residential addresses in both types of areas in the Q2 2018 An Post Geodirectory.

## AVERAGE INDOOR RADON CONCENTRATION BY RADON RISK AREA

See Appendix A.2 for further details.

## SHARE OF NEW RESIDENTIAL BUILDS BY TYPE

Estimates of the shares of housing by dwelling type are sourced from the 2016 Census of Population (Central Statistics Office, 2017). In the absence of any information on the share of new residential buildings by type, we use data on the stock of all permanent dwellings in 2016. Four broad categories of dwelling are identified in the Census: detached, semi-detached, terraced and apartment.[24]

For the analysis of radon risk, it is necessary to further separate out apartments into two separate categories: ground floor and upper floor apartments, as ground floor apartments are likely to be more exposed to radon (which seeps into dwellings through the ground floor; see also Section 1.3). As the Census of Population does not make this distinction, 2019 data from the Housing Agency are used to provide a breakdown of apartments by type (Housing Agency, 2019). Based on a representative survey of the population aged 19+ living in purpose-built apartment blocks in Ireland, 28 per cent of apartment dwellers in the survey are on the ground floor or street level. We use this number to calculate the proportion of apartment dwellers in the 2016 Census who are likely to be ground-floor apartment dwellers.

It is further necessary to identify the shares of complex and simple builds in each category as more complex builds have higher costs for the installation of membranes. We use data from the BER database to calculate the heat loss form factor which is used to proxy the share of complex builds. Form factor is calculated as the total surface (or envelope) area of the house divided by the floor area. This is

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[23] See also https://www.epa.ie/environment-and-you/radon/radon-map/.

[24] See https://data.cso.ie/table/E1051.

calculated by adding the wall area, the floor area and the roof area and then dividing by the floor area.

This is an approximate measure of complexity as more complex builds have higher form factors, but some relatively simple builds (such as long rectangular bungalows) will also have higher form factors. This is because the heat loss form factor is essentially a measure of compactness as opposed to a direct measure of complexity. The maximum value for a form factor is 5 and our threshold value for complexity is 3.8 (this accounts for bungalows that are relatively simple builds but have high heat loss form factors).

We calculate the complex-simple shares of new builds using BER public use data.[25] From this dataset, we take all new builds from the year 2019 (to avoid the effect of the COVID-19 pandemic on building completions). We also exclude any observations where the floor area is below 50m$^2$ as this is the minimum standard of studio apartments in Dublin[26] and can be taken as a reasonable estimate of the minimum floor area for new builds. Once form factors are calculated, we also exclude observations that are over 5 as this is the maximum value for form factors. Form factors valued over this threshold are likely to be the product of extreme values in the dataset.

### AVERAGE GROUND FLOOR AREA OF NEW RESIDENTIAL BUILDS BY TYPE

The estimates for average ground floor area were taken from the Building Energy Rating (BER) database, maintained by the Sustainable Energy Authority of Ireland. The CSO publishes a quarterly report on domestic BER ratings, including the average footprint of residences (by type) with a BER certificate (Central Statistics Office, 2022). For ground-floor and other apartments, we use the footprint values reported for 2015-2019. For detached houses, terraced houses and semi-detached houses, we divide the average footprint for homes built over the period 2015-2019 by two to account for the fact that most of these types of dwelling will be two storeys or higher.[27]

### AVERAGE HOUSEHOLD SIZE

Average household size in private households is sourced from the Census of Population 2016.[28]

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[25] See https://ndber.seai.ie/BERResearchTool/ber/search.aspx.

[26] See https://www.dublincity.ie/dublin-city-development-plan-2016-2022/16-development-standards/1610-standards-residential-accommodation/16101-residential-quality-standards.

[27] See Table 12 for further details.

[28] See https://data.cso.ie/table/E1045.

### AVERAGE TIME SPENT AT HOME

While data from time use surveys can be useful for classifying the average time that individuals spend on different activities (e.g. paid work, leisure, childcare, etc.), they tend not to separately identify the location of the activity (see for example, McGinnity et al. (2005). We therefore use data from a German survey that calculated the average daily time spent indoors in German homes for a study to examine personal exposure to dampness and mould in homes (Brasche and Bischof, 2005). Data from Table 2 in that paper are used to calculate average time spent indoors for three broad age bands: <25, 25-64 and 65+. To reflect potentially greater levels of home working post-pandemic, we run a sensitivity analysis to assess the impact of assuming that the 25-64 age group will spend the same proportion of time at home as the 65+ age group.

### DISCOUNT RATE

Discounting allows the direct comparison of costs and benefits occurring at different points in time, valuing immediate costs and benefits more highly than those that occur later. In line with current guidance from both the Department of Public Expenditure and Reform (Department of Public Expenditure and Reform, 2019) and Health Information and Quality Authority (Health Information and Quality Authority, 2019), a discount rate of 4 per cent is used in this analysis.

### MATERIAL AND INSTALLATION COST PER OPTION

See Appendix A.3 for further details.

### AGE-SPECIFIC LUNG CANCER RISK

The predicted lung cancer risk by age and sex is derived from analysis of National Cancer Registry of Ireland (NCRI) data showing the incidence, survival rates and mortality from lung cancer in Ireland between 1994 and 2019.[29] The baseline demographic risk is derived from the incidence in each age group during the period from 1994-2019, adjusted for an assumed average rate of smoking, former smoking and non-smoking (2006 Eurobarometer estimates[30] are taken to represent the period average) and assumed rates of radon exposure given the population distribution across low, medium and high-radon areas. The population distribution across areas is assumed to have been the same in the historical sample as in the period for which predictions are made. Reflecting improved survival rates for lung cancer over time, the survival rates from lung cancer are based on the latest data from the NCRI, covering the period 2010-2014.

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[29] https://www.ncri.ie/data/incidence-statistics.

[30] Special Eurobarometer 239, Q1.

## REDUCTION IN AVERAGE INDOOR RADON CONCENTRATION BY OPTION

See Appendix A.3 for further details.

## LUNG CANCER RISK PER BQ/M$^3$

Data on lung cancer risk per Bq/m$^3$ are taken from pooled data from 13 European case-control studies, reported in (Darby et al., 2006). That analysis found that there was a linear dose-response relationship between radon and lung cancer risk, with the risk of lung cancer increasing by 16 per cent for every 100 Bq/m$^3$ increase in radon concentration. The dose-response relationship held regardless of the age, sex or smoking status of the individual.[31]

## LIFE EXPECTANCY BY AGE AND SEX

Data on life expectancy by age and sex are taken from the CSO Life Tables for 2016.[32]

## QALE WEIGHTS BY AGE AND SEX

Quality of life expectancy (QALE) weights by age and sex are sourced from a recent publication that estimates QALE weights for the English population, using data from the 2017 and 2018 Health Surveys for England (McNamara et al., 2022).

## INPATIENT AND DAY CASE DISCHARGES PER LUNG CANCER CASE

In 2019, there were 2,702 new cases of lung cancer (ICD-10 code C34 – malignant neoplasm of bronchia and lung) (National Cancer Registry, 2021). To calculate inpatient and day case discharges per lung cancer case in 2019, we divide the total number of inpatient and day case discharges for ICD-10 code C34 in 2019 (sourced from the Hospital Inpatient Enquiry system, HIPE), by the 2019 incidence of lung cancer from the NCR. Data on emergency department (ED) discharges per lung cancer case are sourced from a UK study that estimated the costs of caring for people with cancer at the end of life (Round et al., 2015).

## INPATIENT, DAY CASE AND ED COSTS

Data on average inpatient, day and ED costs per discharge are taken from the ESRI’s Hippocrates model of healthcare demand and expenditure (Figure 5.1 in Keegan et al., 2020).

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[31] Darby et al. (2006) found that when small-cell lung cancers and lung cancers of other histological types were examined separately, there was evidence that the dose-response relationship was steeper for small-cell lung cancer than for other histological types. However, the data we have available do not allow us to distinguish small-cell from other types of lung cancer.

[32] See https://data.cso.ie/table/VSA32.

### GP, OUTPATIENT AND SOCIAL CARE COSTS

Data on GP costs per lung cancer case are calculated by using data from Round et al., 2015 on the average number of GP attendances per annum for a lung cancer case, multiplied by the average cost of a GP visit (Smith et al., 2021; Walsh et al., 2021). The average cost of outpatient care for a lung cancer case is calculated by using data from Round et al., 2015, on the average number of outpatient attendances per annum,[33] multiplied by the average annual cost of an outpatient attendance in 2019 from the ESRI Hippocrates model (Keegan et al., 2020). The cost of other types of care (social, charity, palliative and informal care) is also estimated by using UK data from Round et al., 2015. We calculate the ratio of these costs to total healthcare costs in the UK, and we multiply the ratio by acute healthcare costs calculated for Ireland to impute the cost of social, charity, palliative and informal care required by Ireland's cancer patients.

## A.2 BASELINE RADON CONCENTRATIONS

Mean baseline radon concentrations for each radon risk zone were estimated from 39,918 observations of microdata on radon test results provided to the study team by the EPA. When calculating mean values, the sample was weighted to allow for geographical variations in sampling intensity. This was done to allow for the possibility that there was sample selection bias in testing; in particular, sampling might have been higher in areas flagged as high risk in the previous radon map. Inverse probability weights were generated using Stata's *ipfweight* command, comparing the sample shares of radon tests in the three radon risk zones with the distribution of residences reported in the Q2 2018 An Post Geodirectory.

## A.3 TECHNICAL SPECIFICATIONS, COSTS AND BENEFITS OF BASELINE AND POLICY OPTIONS

A review of the technical specifications on membranes in Technical Guidance Document C (TGD-C), as well as consultation with construction companies, quantity surveyors, officials in the Department of Housing, Local Government and Heritage and their counterparts in Northern Ireland and Britain allowed the research team to define the technical specifications, and associated costs, for each option in greater detail. Information on the relative benefits of different radon protection measures is sourced from previous literature.

Section 1.4 set out the requirements for radon and damp-proof membranes in Ireland as per TGD-C (Department of Housing, Local Government and Heritage, 1997). Scivyer (2015) sets out the requirements for radon protection in new buildings in the UK. In areas with increased radon potential, sufficient protection is

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[33] The number of outpatient visits is not disaggregated by cancer type (see Table 2 in Round et al., 2015).

provided by a well-installed 1200 gauge damp-proof membrane (DPM) modified and extended to form a radon barrier across the footprint of the building. This gas-tight barrier is known as 'basic radon protection'. New buildings in areas of higher radon potential should incorporate full radon protection comprising a radon barrier across the footprint of the building supplemented by provision for subfloor depressurisation or ventilation (either a radon sump or a ventilated subfloor void). Table A.2 describes the three policy options that are evaluated in this study.

**TABLE A.2 TECHNICAL SPECIFICATIONS FOR BASELINE AND POLICY OPTIONS**

| | Baseline | Option 1 | Option 2 | Option 3 |
|---|---|---|---|---|
| **Description** | Sealed radon membrane in high radon areas (HRAs), and unsealed damp-proof membrane in non-high radon areas (non-HRAs) | Sealed radon membrane in all areas | Sealed damp-proof membrane in non-HRAs | Sealed damp-proof membrane in all areas |
| **Difference to baseline** | - | Extension of radon membrane to non-HRAs | For non-HRAs, requirement for damp-proof membrane to be sealed; requirement unchanged for HRAs | For non-HRAs, requirement for damp-proof membrane to be sealed; for HRAs, replacement of a radon membrane with a sealed damp-proof membrane |

*Source:* Adapted from Department of Housing, Local Government and Heritage (1997) by the authors.

Costs and benefits for radon, sealed damp-proof and unsealed damp-proof membranes are outlined in Table A.3. Costs are differentiated by building type and complexity and a weighted average (expressed per sq/m) is calculated. Costs refer to the material and installation (i.e. labour) costs of the membrane (excluding VAT). The benefit (i.e. average reduction in indoor radon concentration) is sourced from previous cost effectiveness analyses of radon prevention measures in new homes that estimated that radon (and appropriately sealed damp-proof) membranes result in an average reduction in indoor radon concentrations of 50 per cent (Gaskin et al., 2018b; Gray et al., 2009; Health Protection Agency, 2009; Pollard and Fenton, 2014). There is wide variability in average reductions in indoor radon concentrations in individual studies that compare measurements before and after installation of membranes (see for example, Denman et al., 2018; Dowdall et al., 2017; Khan et al., 2019; Long et al., 2013), but we follow standard practice of assuming a 50 per cent average reduction. In the sensitivity analysis detailed in Chapter 3, we also assess the cost-effectiveness of the various policy options assuming a lower (30 per cent) reduction in indoor radon concentration for a sealed damp-proof membrane. However, we note that this is an illustrative exercise and not evidence-based.

### TABLE A.3 COSTS AND BENEFITS OF RADON AND DAMP-PROOF MEMBRANES

| | Sealed Radon Membrane | Sealed Damp-Proof Membrane | Unsealed Damp-Proof Membrane |
|---|---|---|---|
| **Costs**[34] | €8.66 per sq/m | €4.36 per sq/m | €3.27 per sq/m |
| **Benefits** | 50% reduction in indoor radon concentration | 50% reduction in indoor radon concentration | No change in indoor radon concentration |

*Source:* Authors' analysis.

## A.4 TRENDS IN NEW RESIDENTIAL BUILDING AND DEMOGRAPHY

Housing demand projections were obtained from Bergin and Garcia Rodriguez (2020) and are based on regional demographic projections and assumptions about housing obsolescence and headship rates. The two options modelled are for baseline and high international migration scenarios. The projections are at county level and come from the housing demand report above. At a national level, housing demand is expected to be 28,000 per annum in a baseline/'business as usual' scenario over the medium term and around 33,000 per annum in a high international migration scenario. Assumptions about the age distribution of the population are taken from Central and High population scenarios in Keegan et al., 2022.

## A.5 SCENARIOS FOR FUTURE SMOKING PREVALENCE

### Overview

This model aims to project the evolution of smoking rates over the total population of Ireland over time in line with Health Service Executive (HSE) targets to reduce smoking prevalence. The model uses population forecast figures (see above) and smoking rates from 2018 for both adult and youth populations to create a scenario in which the targets set out in Healthy Ireland, the strategic framework for health and wellbeing in Ireland, and Tobacco Free Ireland, the national tobacco control policy, are achieved (Department of Health, 2013; Government of Ireland, 2013). Over time, it projects a 1 percentage point decrease in smoking rate per annum among adults and youth populations. Lower smoking rates among youth populations in turn mean that fewer young people become adult smokers over time.

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[34] These figures include both the material and labour costs of installation. It is not possible to separate out the various components in detail, but consultation with industry suggested that labour costs do not differ by type of membrane, but rather by the extent of sealing and the complexity of the build.

## Parameters

### *Target Rates of Smoking*

Healthy Ireland and Tobacco Free Ireland document the targets for reducing the smoking rate by 1 percentage point per annum. This goal was set in 2013 with a view to reduce smoking to 5 per cent of the population by 2025 (Department of Health, 2013; Government of Ireland, 2013). Although it is now evident that there will not be a 5 per cent rate of smoking by 2025, we assume in our model that there is a scenario where the 1 percentage point decrease per annum holds. We also assume that once the adult smoking rate reaches 5 per cent that it will remain stable. For youth smoking rates, the Department of Health is targeting a similar rate of decline over time: 1 percentage point per annum decrease in smoking initiation rates (i.e. fewer young people take up smoking at all, over time). However, there is no lower bound of the smoking rate for youth populations (Government of Ireland, 2013).

### *Smoking Prevalence*

Our model assumes that there are three subsets of the adult population: current smokers, former smokers and never smokers. This model also assumes the following pathways between the categories:

a) Current smokers can become former smokers;

b) Current smokers and former smokers cannot become never smokers;

c) Never smokers will not become current or former smokers.

The last assumption may seem unrealistic, but as most smoking initiation starts in adolescence (Department of Health, 2013; European Commission, 2021), it is not unreasonable to assume that adults do not subsequently take up smoking.

Data on current smoking prevalence are sourced from the HSE (Evans et al., 2018; Sheridan et al., 2018). The smoking rates that the HSE reported in 2018 were two-fold: one set of rates for adults (current, former and never smokers) and a current smoking rate for those aged 18 and under. Therefore, our model makes the assumption that there are no former smokers among the population under the age of 18. This is a simplistic assumption but one that must be made in the absence of data on rates of quitting among youth populations. Table A.4 summarises the various parameters used in our model.

TABLE A.4 SMOKING PARAMETERS

| Parameter | Value |
|---|---|
| **National targets** | Adults: 1 percentage point decline per annum<br>Children and young people: 1 percentage point decline in smoking initiation per annum |
| **Smoking Rates for Adults** | Current smoker: 23% |
| | Former smoker: 28% |
| | Never smoker: 49% |
| **Smoking Rates for Children and Young People** | 18 years old: 20% |
| | 15-17 years old: 14% |
| | 12-14 years old: 4% |
| | 10 – 12 years old: 1% |
| | <=9 years old: 1% |

*Source:* Authors' analysis.

## Methodology

The analysis uses projected population figures to project the size of the smoking population in each year. As the population data are divided into 5-year age bands, starting from 0-4 and ending with an 85+ category, the adult population in the smoking model is defined as those aged 20+.[35] The calculation of the smoking population (current, former and never) is done in the following way:

- The *current smoking adult population (20+)* is calculated simply by multiplying the smoking rate in year $x$ by the adult population in year $x$.
- The *former smoking adult population (20+)* is calculated by subtracting the current smoking adult population in year $x$ from the total smoking and former smoking population in the previous year $(x - 1)$. This includes 18-19 years old smokers from year $x - 1$.
- The *never smoking adult population (20+)* is then calculated as a residual.
- The *current smoking population aged under 20* for year $x$ is calculated by multiplying the smoking rate in year $x$ for each age band by the population in that age band.

## Scenarios

There are two scenarios we use as inputs into the model: (1) Healthy Ireland and Tobacco Free Ireland strategies; (2) a slower decline in smoking rates. The first scenario assumes a 1 percentage point decrease in smoking rates per year, in line

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[35] The smoking rates for children and young people from Table A.4 do not fully align with these 5-year age bands, so a number of approximations were made to align the smoking data to the model:

- The under 9 smoking rate was applied to the 0-4 and 5-9 population age bands;
- An average of the 10-12 years old and 12-14 years old smoking rate was applied to the 10-14 age band;
- The smoking rate for 15-17 years olds was applied to three-fifths (60 per cent) of the population aged between 15-19, while the 18 years old smoking rate was applied to two-fifths (40 per cent) of the population aged between 15-19.

with national targets. The second scenario assumes a slower 0.5 percentage point decrease in smoking rates per annum.

## A.6 PROJECTED UNIT COSTS OF HEALTH SERVICES

To project the benefits arising from avoided costs of health services, an annual cost per case of healthcare is needed. Healthcare unit costs have historically tended to rise more quickly than inflation, leading to annual increases in real terms. In this model, costs for three types of acute care (day case, inpatient and emergency department) were divided into categories covering pay, pharmaceuticals and 'other' to allow for varying rates of unit cost growth in real terms. Base year unit costs were obtained from Keegan et al. (2020; Figure 5.1). Two scenarios for the rate of growth for each category in real terms were also sourced from Table 3.1 in the same report, one based on the 'Recovery' scenario and one involving lower rates of growth called 'Delayed Recovery'. The base year costs are inflated using these real growth rates to provide unit cost projections for future years. Unit costs for other health and social care services required by cancer patients, including outpatient services, GPs and imputed costs of social, charity, palliative and informal care services, are assumed to be constant in real terms.

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