Report No. 439

epa Research

Research on the Environment, Health, Consumer Behaviour and the Economy: ESRI Research Programme on Environmental Socio-economics 2020–2022

Authors: Ylva Andersson, Peter Barlow, Philip Carthy, Kelly de Bruin, Míde Griffin, Seán Lyons, Pete Lunn, Bertrand Maître, Likun Mao, Maria Martinez Cillero, David Meier, Gretta Mohan, Kieran Mohr, Anne Nolan, Brian O’Connell, Vincent O’Sullivan, Aidan Sloyan, Shane Timmons, Miguel Tovar Reaños, Brendan Walsh and Aykut Mert Yakut

www.epa.ie

Rialtas na hÉireann
Government of Ireland

Environmental Protection Agency

The EPA is responsible for protecting and improving the environment as a valuable asset for the people of Ireland. We are committed to protecting people and the environment from the harmful effects of radiation and pollution.

The work of the EPA can be divided into three main areas:

Regulation: Implementing regulation and environmental compliance systems to deliver good environmental outcomes and target those who don't comply.

Knowledge: Providing high quality, targeted and timely environmental data, information and assessment to inform decision making.

Advocacy: Working with others to advocate for a clean, productive and well protected environment and for sustainable environmental practices.

Our Responsibilities Include:

Licensing

> Large-scale industrial, waste and petrol storage activities;
> Urban waste water discharges;
> The contained use and controlled release of Genetically Modified Organisms;
> Sources of ionising radiation;
> Greenhouse gas emissions from industry and aviation through the EU Emissions Trading Scheme.

National Environmental Enforcement

> Audit and inspection of EPA licensed facilities;
> Drive the implementation of best practice in regulated activities and facilities;
> Oversee local authority responsibilities for environmental protection;
> Regulate the quality of public drinking water and enforce urban waste water discharge authorisations;
> Assess and report on public and private drinking water quality;
> Coordinate a network of public service organisations to support action against environmental crime;
> Prosecute those who flout environmental law and damage the environment.

Waste Management and Chemicals in the Environment

> Implement and enforce waste regulations including national enforcement issues;
> Prepare and publish national waste statistics and the National Hazardous Waste Management Plan;
> Develop and implement the National Waste Prevention Programme;
> Implement and report on legislation on the control of chemicals in the environment.

Water Management

> Engage with national and regional governance and operational structures to implement the Water Framework Directive;
> Monitor, assess and report on the quality of rivers, lakes, transitional and coastal waters, bathing waters and groundwaters, and measurement of water levels and river flows.

Climate Science & Climate Change

> Publish Ireland's greenhouse gas emission inventories and projections;
> Provide the Secretariat to the Climate Change Advisory Council and support to the National Dialogue on Climate Action;
> Support National, EU and UN Climate Science and Policy development activities.

Environmental Monitoring & Assessment

> Design and implement national environmental monitoring systems: technology, data management, analysis and forecasting;
> Produce the State of Ireland's Environment and Indicator Reports;
> Monitor air quality and implement the EU Clean Air for Europe Directive, the Convention on Long Range Transboundary Air Pollution, and the National Emissions Ceiling Directive;
> Oversee the implementation of the Environmental Noise Directive;
> Assess the impact of proposed plans and programmes on the Irish environment.

Environmental Research and Development

> Coordinate and fund national environmental research activity to identify pressures, inform policy and provide solutions;
> Collaborate with national and EU environmental research activity.

Radiological Protection

> Monitoring radiation levels and assess public exposure to ionising radiation and electromagnetic fields;
> Assist in developing national plans for emergencies arising from nuclear accidents;
> Monitor developments abroad relating to nuclear installations and radiological safety;
> Provide, or oversee the provision of, specialist radiation protection services.

Guidance, Awareness Raising, and Accessible Information

> Provide independent evidence-based reporting, advice and guidance to Government, industry and the public on environmental and radiological protection topics;
> Promote the link between health and wellbeing, the economy and a clean environment;
> Promote environmental awareness including supporting behaviours for resource efficiency and climate transition;
> Promote radon testing in homes and workplaces and encourage remediation where necessary.

Partnership and Networking

> Work with international and national agencies, regional and local authorities, non-governmental organisations, representative bodies and government departments to deliver environmental and radiological protection, research coordination and science-based decision making.

Management and Structure of the EPA

The EPA is managed by a full time Board, consisting of a Director General and five Directors. The work is carried out across five Offices:

1. Office of Environmental Sustainability
2. Office of Environmental Enforcement
3. Office of Evidence and Assessment
4. Office of Radiation Protection and Environmental Monitoring
5. Office of Communications and Corporate Services

The EPA is assisted by advisory committees who meet regularly to discuss issues of concern and provide advice to the Board.

Research on the Environment, Health, Consumer Behaviour and the Economy: ESRI Research Programme on Environmental Socio-economics 2020–2022

Authors: Ylva Andersson, Peter Barlow, Philip Carthy, Kelly de Bruin, Míde Griffin, Seán Lyons, Pete Lunn, Bertrand Maître, Likun Mao, Maria Martinez Cillero, David Meier, Gretta Mohan, Kieran Mohr, Anne Nolan, Brian O'Connell, Vincent O'Sullivan, Aidan Sloyan, Shane Timmons, Miguel Tovar Reaños, Brendan Walsh and Aykut Mert Yakut.

Identifying pressures

The EPA/ESRI Research Programme on Environmental Socio-economics brings together a diverse set of research topics with the aim of producing policy-relevant applied research at the interface between the environment, economy and society. A range of data and methodological approaches are used to provide insights into the environmental challenges facing Irish society. This report provides a detailed summary of the 12 topics examined in the third phase of the programme, which was carried out between 2020 and 2022. These topics can be grouped under four broad themes:

1. environment and health;
2. behavioural science;
3. biodiversity and agriculture;
4. climate change.

The findings from the project Measuring the Health and Well-being Benefits of being a Citizen Scientist, which spanned phases 2 and 3 of the research programme, are also summarised in this report.

Informing policy

Research on drinking water quality and its effects on population health found that, while the burden on the acute healthcare system in Ireland from water-related diseases (WRDs) is relatively moderate, WRDs disproportionately affect younger people and a small number of rural or children's hospitals during the spring and summer. This finding in particular will allow limited public health resources to target specific regions at certain times of the year to further reduce morbidity and the costs associated with WRDs.

While governments introduce taxes and incentives to deter emissions contributing to climate change, these policies focus on reducing national (production) emissions and not the global level of emissions. The research shows that the emissions embedded in Irish imports are extremely large, resulting in consumption-based emissions being more than double production-based emissions. Policymakers need to look beyond our borders and consider the emissions that our consumption patterns create in other nations.

Developing solutions

The way information is presented affects the extent to which people attend to that information and also the choices they make. Using insights from behavioural science, the research provided evidence for policymakers and public bodies tasked with communicating with the general public about different environmental risks and behaviours. For example, the project on radon testing found that understanding of the risk from radon can be improved by a strategy that provides households with more information about radon, and also communicates risk statistics using numerical frequencies. In addition, careful pre-testing of the design features of a radon risk map (including numerical frequencies, e.g. "1 in 5 homes") results in substantially more people who are highly willing to test their home for radon. The redesigned map has now been adopted by the EPA.

EPA RESEARCH PROGRAMME 2021–2030

Research on the Environment, Health, Consumer Behaviour and the Economy: ESRI Research Programme on Environmental Socio-economics 2020–2022

(2020-HW-MS-18)

EPA Research Report

Prepared for the Environmental Protection Agency

by

Economic and Social Research Institute

Editor: Anne Nolan

Authors:

Ylva Andersson, Peter Barlow, Philip Carthy, Kelly de Bruin, Míde Griffin, Seán Lyons, Pete Lunn, Bertrand Maître, Likun Mao, Maria Martinez Cillero, David Meier, Gretta Mohan, Kieran Mohr, Anne Nolan, Brian O'Connell, Vincent O'Sullivan, Aidan Sloyan, Shane Timmons, Miguel Tovar Reaños, Brendan Walsh and Aykut Mert Yakut

ENVIRONMENTAL PROTECTION AGENCY
An Ghníomhaireacht um Chaomhnú Comhshaoil
PO Box 3000, Johnstown Castle, Co. Wexford, Ireland

Telephone: +353 53 916 0600 Fax: +353 53 916 0699
Email: info@epa.ie Website: www.epa.ie

ACKNOWLEDGEMENTS

This report is published as part of the EPA Research Programme 2021–2030. The EPA Research Programme is a Government of Ireland initiative funded by the Department of the Environment, Climate and Communications. It is administered by the Environmental Protection Agency, which has the statutory function of co-ordinating and promoting environmental research.

The authors would like to acknowledge the members of the project steering committee, namely Eimear Cotter (EPA), Jonathan Derham (EPA), Micheál Lehane (EPA), Aisling O'Connor (EPA), Alice Wemaere (EPA), Tara Higgins (EPA), John McEntagart (Project Manager on behalf of EPA Research) and John Curtis (Economic and Social Research Institute). The authors would also like to thank the Central Statistics Office, the Health Service Executive, the Irish Longitudinal Study on Ageing (TILDA) and the EPA for providing data for the analyses in this report.

EPA RESEARCH PROGRAMME 2021–2030
Published by the Environmental Protection Agency, Ireland

ISBN: 978-1-80009-131-3 October 2023

Price: Free Online version

Project Partners

Anne Nolan
Economic and Social Research Institute
Whitaker Square
Sir John Rogerson's Quay
Dublin
Ireland
D02 K138
Tel.: + 353 (0)1 863 2022
Email: Anne.Nolan@esri.ie

Contents

List of Figures

List of Tables

Executive Summary

Continuing the collaboration established between the Economic and Social Research Institute and the EPA in Phase I (2016–2018) (Lyons, 2019) and Phase II (Nolan, 2020) of the Research Programme on Environmental Socio-economics, this report summarises the findings from Phase III of the programme (2020–2022). The broad objective of the programme is to produce policy-relevant applied research at the interface between the environment and economy/society. A diverse set of research topics was examined in Phase III, broadly grouped under four thematic areas (environment and health; behavioural science; biodiversity and agriculture; climate change), with an additional study on environmental citizen science from Phase II concluding in 2022.

Environment and Health

Five studies, using data from a variety of survey and administrative sources, were carried out to examine the impact of air and water quality on population health, healthcare utilisation and healthcare costs.

Smoky Coal Bans and Health Smoky coal bans in towns in Ireland over the period 2010–2018 reduced the probability of a lung disease diagnosis in the older population, although no effect on mortality has yet been identified.

Long-run Exposure to $PM_{2.5}$ Air Pollution and Mental Health Living in an area with higher $PM_{2.5}$ (particulate matter consisting of particles with a diameter of 2.5 μm or less) concentrations over the previous 17 years was associated with an increase in the prevalence of both depression and anxiety in the older population, but no association was detected with other indicators of wellbeing, such as worry, stress or quality of life.

Solid Fuel Heating Use and Health Outcomes The use of solid fuels for residential heating varies substantially across the country, with residents in the Border, Midland and Western region significantly more likely to use solid fuels for heating than residents in Dublin. Solid fuel use was associated with an increased incidence of circulatory and respiratory disease in the older population.

Drinking Water Quality and Healthcare Utilisation of Older People Drinking water exceedances of standards for *Escherichia coli* were found to be associated with higher utilisation of general practitioner and acute hospital care among the older population.

Healthcare Costs of Water-related Diseases Using administrative data on hospital inpatients, the acute care cost of water-related diseases in Ireland was estimated to be between €8 million and €25 million over the 4-year period 2015–2018. The burden of disease varies significantly by time of year, hospital and population group, with a small number of rural and children's hospitals during the spring and summer months particularly affected.

Behavioural Science

Three studies employed techniques from behavioural science to design and test regulatory communications for use by the EPA.

Behavioural Pre-testing of Radon Risk Maps The study showed that, compared with the pre-existing radon risk map, substantially more people reported being very willing to test their home for radon after using a map that communicated risk using numerical frequencies (e.g. "1 in 5 homes at risk" rather than "homes are at high risk"), had three categories of risk (low, moderate, high), used a typical yellow to red colour scheme and had search functionality.

Diagnostic Experiment on Household Waste Management While attitudes among the public towards proper household waste management are broadly positive, there is considerable scope for improving identification of non-recyclable composites (e.g. mixed-material packaging, laminated paper and crisp tubes). For these items, high-level abstract communication is unlikely to help, and item-specific feedback may be more beneficial.

Diagnostic Experiment on Youth Communications The results show that highlighting generational differences in the causes and effects of climate change leads to higher levels of worry among young people, compared with standard information on climate change. A large majority (three in four) of young people underestimate the level of worry that older people report. The findings imply that communications about climate change should emphasise similarities in concern between subgroups of the population, rather than emphasising differences.

Biodiversity and Agriculture

Based on analyses of the National Farm Survey, the research used a variety of methods to examine the effect of alternative agricultural subsidy designs on beef and dairy farm performance and on labour supply.

Designing a Green, Equitable and Socially Acceptable Subsidy Scheme The research identifies a positive relationship between technical efficiency and the Green, Low-Carbon, Agri-Environment Scheme for dairy farms, in contrast with the negative relationship identified for previous payments of this kind, such as the Rural Environment Protection Scheme for both beef and dairy farms. When designing environmental payment schemes, policymakers need to consider that effects may differ across farm types.

Farm Labour Supply and Farm Technical and Environmental Efficiency The results show that agricultural subsidies should be designed with not only their direct impacts but also their indirect effects on farm efficiency and environmental emissions in mind (e.g. farm labour supply). Since agricultural subsidies are associated with more off-farm work, which in turn is positively associated with environmental efficiency, their effects could be more significant than initially expected.

Climate Change

While governments introduce taxes and incentives to deter emissions contributing to climate change, these policies focus on reducing production-based emissions and not consumption-based emissions. The two projects under the climate change theme aimed to create a better understanding of the emissions embedded in our consumption and how we may regulate these emissions.

Consumption-based Greenhouse Gas Emissions The results show that the emissions embedded in imports are extremely large in Ireland, resulting in consumption-based emissions being more than double production-based emissions.

Green VAT Reform An alternative design of the value added tax (VAT) schedule (“green VAT”), to take account of emissions embedded in consumption, would be effective in reducing emissions by lowering consumption but without revenue recycling could reduce labour supply and income tax revenue. This highlights the need for policymakers to consider the trade-offs between the distributional, economic and environmental impacts of different policy packages.

Environmental Citizen Science

Continuing the partnership with the National Biodiversity Data Centre, data from a follow-up survey of biodiversity data recorders showed that the respondents reduced their social activities during the COVID-19 pandemic, although their physical health and activity levels did not change on average. In addition, a greater proportion of respondents reported climate change as one of their top four environmental concerns.

1 Introduction

The EPA and Economic and Social Research Institute (ESRI) Research Programme on Environmental Socio-economics brings together a diverse set of research topics with the objective of assessing the ways in which the environment interacts with economic and social processes. The programme has at its core the ambition to produce fast and focused policy-relevant analysis that employs publicly available data in new ways and through the generation of policy-relevant behavioural insights. Lyons (2019) and Nolan (2020) provide detailed summaries of the topics examined in the first (2016–2018) and second (2018–2020) phases of the programme. In this report, we synthesise the results from the third phase of the programme, which comprised 12 studies carried out between 2020 and 2022. An additional study on environmental citizen science from Phase II, which involved a follow-up survey carried out in 2021, was also completed in Phase III. These studies can be grouped as follows:

- Environment and health:
  - smoky coal bans and health;
  - long-run exposure to $PM_{2.5}$ (particulate matter consisting of particles with a diameter of 2.5 μm or less) air pollution and mental health;
  - solid fuel heating use and health outcomes;
  - drinking water quality and healthcare utilisation of older people;
  - healthcare costs of water-related diseases.
- Behavioural science:
  - behaviour pre-testing of radon risk maps;
  - diagnostic experiment on household waste management;
  - diagnostic experiment on youth communications.
- Biodiversity and agriculture:
  - designing a green, equitable and socially acceptable subsidy scheme;
  - farm labour supply and farm technical and environmental efficiency.
- Climate change:
  - consumption-based greenhouse gas (GHG) emissions;
  - green value added tax (VAT) reform.
- Environmental citizen science.

The research topics for Phase III were selected through a process of dialogue with the EPA and other stakeholders (e.g. Department of the Environment, Climate and Communications). In some cases, e.g. on the health and environment theme, the work further developed the research carried out in Phases I and II. Other themes, e.g. research on climate change, involved new research, using new data sources and methods. Throughout, as in Phases I and II, the partners sought to identify research questions and themes that offered policy relevance and scope for robust empirical analysis.

It is worth summarising the diversity of data and methodological approaches used in the research programme, as it highlights the uses of different approaches for policy analysis and development. First, by combining individual-level survey data with spatially coded administrative data on environmental conditions, we can better understand the impact of environmental conditions on health and wellbeing. In this phase of the programme, we continued to use survey data from the Irish Longitudinal Study on Ageing (TILDA), linked to additional environmental exposures such as smoky coal ban areas, historical $PM_{2.5}$ exposures and drinking water quality test results. The use of individual-level data means that confounding factors, such as socio-economic status, can be taken into account. This allows us to generate more robust insights into the relationship between the environment and health and wellbeing.

Second, the research team has also made use of administrative data to provide additional insights. For example, data from the Hospital In-Patient Enquiry (HIPE) system were used in this phase of the programme to provide estimates of the acute healthcare costs of poor drinking water quality. The availability of detailed clinical data on patients treated in acute hospitals facilitated an analysis of variation in the incidence and treatment costs of waterborne diseases across population groups, regions and time of year. Administrative data on cross-border trade flows were also a key input in the calculation of consumption-based GHG emissions in Ireland.

Third, where survey and administrative data are not available, new data collection can provide insights into hitherto under-researched population groups. In collaboration with the National Biodiversity Data Centre (NBDC), we designed a follow-up questionnaire to assess how our sample of biodiversity data recorders (who signed up with the NBDC in 2019) fared over the first 2 years of their recording experience, which also included their experience during the COVID-19 pandemic.

Last, the use of behavioural science techniques, such as laboratory experiments and field trials, which involves the collection of new data, offers an opportunity to influence the design of policy interventions. In this phase of the programme, three topics were the subject of analysis: the design of an alternative radon risk map, the design of youth communication materials, and effective strategies for communicating with the public on waste management.

Much of the research carried out under this phase of the programme has been submitted for publication in peer-reviewed journal articles, with a number of articles already published. In these cases, we summarise the research in this report; additional material can be found in the full publications, which are referenced in each section. In other cases, research has only recently been completed and is awaiting publication, and so this report contains a more detailed account of the work.

2 Environment and Health

Research described in this chapter was carried out by Peter Barlow, Philip Carthy, Míde Griffin, Seán Lyons, Bertrand Maître, Likun Mao, Gretta Mohan, Anne Nolan, Brian O'Connell, Vincent O'Sullivan, Aidan Sloyan and Brendan Walsh.

2.1 Introduction

The natural and built environment is an important component of the "social determinants of health", i.e. the non-medical factors that determine our health and wellbeing throughout the life course. In Phase I of the EPA/ESRI research programme, the research team pioneered the use of linked environment–health data at the individual level to examine the impact of radon risk on lung cancer (Dempsey *et al*., 2018a), the impact of urban green spaces on obesity (Dempsey *et al*., 2018b) and the impact of coastal blue spaces on mental health (Dempsey *et al*., 2018c). For these analyses, individual-level data on health and socio-economic characteristics from TILDA were matched with spatially coded data on environmental exposures from a variety of sources, such as the EPA, EU Urban Atlas and Ordnance Survey Ireland (now known as Tailte Éireann). The use of individual-level data allows us to control for many confounding factors, such as socio-economic position, and thus come up with more robust estimates of the impact of selected environmental exposures on health and wellbeing.

In Phase II of the EPA/ESRI research programme, we extended the research carried out in Phase I in a number of ways. First, we carried out further research on the impact of green spaces on obesity to try to understand the mechanisms underlying the observed U-shaped relationship between green space and obesity in Ireland (Carthy *et al*., 2020). Second, we examined the impact of additional environmental exposures, such as air pollution (Carthy *et al*., 2021). Last, we used another source of survey data, the Healthy Ireland Survey, to examine how subjective perceptions and objective measurements of area-level quality are related (Barlow *et al*., 2021).

In Phase III, we further extended this body of research to examine the impact of long-run environmental exposures on health (sections 2.2 and 2.3), the socio-economic distribution of environmental exposures and poor health (section 2.4) and the effect of poor drinking water quality on health (section 2.5). For the first time, administrative data on health were also used to add to the body of evidence in this area, using data from the HIPE system to calculate the acute healthcare costs of waterborne diseases in Ireland (section 2.6).

2.2 Smoky Coal Bans and Health

The research described in this section was carried out by Seán Lyons, Likun Mao (University of Aberdeen), Anne Nolan and Vincent O'Sullivan (University of Limerick).

2.2.1 *Background*

Globally, coal is still widely used for heating. Ireland sources nearly 17% of energy for residential heating from solid fuels (peat, coal, etc.), a figure that is considerably higher than the EU average of 4%.[1] There are concerns about the effect of solid fuel use on ambient (outdoor) air quality and health. The World Health Organization (WHO) estimates that 3 million deaths every year are a result of ambient air pollution (WHO, 2016). Although air pollution has decreased in most European countries over the past two decades, levels of air pollution remain above WHO guidelines in many cities and towns in Ireland (EPA, 2022).

Starting in 1990, Ireland implemented a series of "smoky coal bans" in different areas of the country. Using data from TILDA, this research examines the effect of the roll-out of smoky coal bans across the country over the period 2010–2018 on the prevalence of lung disease and mortality in the older population.

1 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_consumption_in_households#Energy_products_used_in_the_residential_sector (accessed 15 August 2023).

As the roll-out of the bans was based on population size, rather than other factors that might confound the association between the ban and health outcomes (i.e. the introduction of a ban in a particular town was not directly in response to high pollution levels in that town), the results provide robust estimates of the independent effect of smoky coal bans on population health.

2.2.2 Data and methods

Survey data from the first five waves of TILDA, covering the period 2010–2018, are the main source of data used in this study. The main outcome of interest is the prevalence of lung disease, i.e. chronic lung diseases such as chronic bronchitis and emphysema. In each wave of TILDA participants were asked if they had ever been diagnosed with chronic lung disease. In a secondary analysis, we also examined the effect of the ban on all-cause mortality.

To identify the effect of the ban, the addresses of the TILDA participants were matched to their electoral division, as the legislation concerning smoky coal bans defines the area covered by the ban in terms of electoral divisions. These data are then matched to a database that describes the roll-out of smoky coal bans across different areas of the country over the period 2010–2018. Figure 2.1 illustrates the roll-out of the smoky coal bans across towns and cities in Ireland over this period.

Using five waves of TILDA data, a statistical model was estimated that explores the relationship between living in an area covered by a smoky coal ban and lung disease, while also controlling for other demographic and socio-economic factors that might explain the prevalence of lung disease, such as age, sex, education level, housing quality, etc. A second model examined the relationship between living in an area covered by a smoky coal ban and all-cause mortality. The sample size of deaths in TILDA is too small at present to disaggregate all-cause mortality into different causes of death.

2.2.3 Results

Table 2.1 presents the main results for the model of lung disease. The average marginal effect of the ban is to reduce the prevalence of lung disease by 4.8 percentage points, and this effect is statistically significant at the 5% level. The results show that men are 4.1 percentage points less likely to have lung disease than women. In the past, lung disease was seen as a disease that affected older men; however, recent studies have shown that this is changing (Barnes, 2016). Age is a risk factor for lung disease; getting older increases the probability of lung disease by 0.2 of a percentage point each year. Furthermore, wealthier people and those with higher levels of education are less likely to have lung disease. Smoking either in the past or at the time of the survey has a positive effect on the probability of lung disease. Similarly, those who experienced poor health when they were younger (the question asks the participant to recall their health from birth to age 14 years) are more likely to have lung disease. One anomalous finding is that growing up in an urban area is associated with a lower probability of developing lung disease. This finding may be explained by the fact that, in Ireland, in the TILDA sample, the exposure of people to indoor pollution in the home may have been greater for rural dwellers who belong to the generations who grew up in rural areas without electricity before the mid-1960s. In 1946, two-thirds of Irish homes, mostly in rural

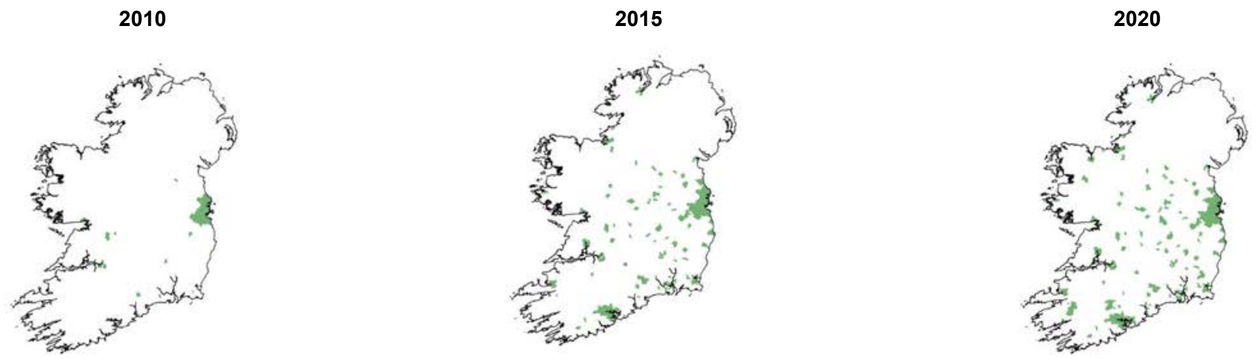

Figure 2.1. Timing of smoky coal bans across towns in Ireland.

Table 2.1. Average marginal effect (AME) of relevant characteristics on probability of lung disease

Characteristic	AME (standard error)
Living in area with smoky coal ban	–0.048 (0.018)**
Male	–0.041 (0.015)***
Age	0.002 (0.001)***
Education (reference category: primary)	
Secondary	–0.040 (0.024)*
Post secondary	–0.016 (0.026)
Wealth (reference category: first quintile)	
Second quintile	0.004 (0.010)
Third quintile	–0.002 (0.011)
Fourth quintile	–0.046 (0.019)
Fifth quintile	–0.019 (0.017)
Refused/do not know	0.001 (0.011)
Smoker (reference category: never)	
Past	0.056 (0.013)***
Current	0.049 (0.019)**
Health when young (reference category: excellent)	
Very good	0.018 (0.017)
Good	0.013 (0.022)
Fair	0.060 (0.024)**
Poor	0.103 (0.040)***
Lived away from Ireland	–0.006 (0.015)
Lived in urban area when young	–0.034 (0.012)***
Family finances when young (reference category: well-off)	
Average	0.003 (0.025)
Poor	0.031 (0.026)
Do not know	–0.016 (0.043)
Refused	0.003 (0.025)
Log of population density	0.027 (0.044)
Years lived in home	–0.002 (0.001)**
Year home built (reference category: before 1919)	
1919–1940	–0.044 (0.035)
1941–1960	–0.055 (0.047)
1961–1970	–0.032 (0.046)
1971–1980	–0.053 (0.050)
1981–1990	–0.039 (0.045)
1991–2000	–0.071 (0.063)
2001 or later	–0.077 (0.049)
Do not know	–0.059 (0.046)

*****, ** and * correspond to significance at the 1%, 5% and 10% level, respectively.**

areas, did not have electricity, and so both heating and cooking relied on solid fuels (Shiels, 2003). Thus, the positive association between growing up in a rural area and lung disease in later life could be due to greater exposure to harmful indoor pollution.

In relation to the local area characteristics, population density does not have a significant effect on lung disease. However, participants' housing does affect the probability of lung disease. For example, the number of years lived in the home has a negative effect. This negative effect of years lived in the home could represent reverse causality. Perhaps people move house if they are suffering from lung disease, either because they believe that housing conditions (e.g. dampness) affect their health or because they want to have a home that is easier to live in (e.g. easier mobility within the home or outside the home in the local area). In relation to the age of the home, we found that people who live in older homes are more likely to develop lung disease (a finding most likely to be explained by improvements in building standards over time having a positive effect on health), although this effect is not statistically significant.

While not shown here, the results for all-cause mortality show that there is no statistically significant relationship between living in an area with a smoky coal ban and all-cause mortality. However, it is likely that there may be a longer lag between the implementation of a smoky coal ban and improvements in mortality, and, as noted, it was not possible to examine detailed causes of death rather than all-cause mortality due to sample size constraints.

2.2.4 Conclusions and policy implications

Using five waves of data from TILDA, matched to data on the roll-out of smoky coal bans across different areas of the country over the period 2010–2018, this research showed that the bans resulted in a significant reduction in the prevalence of lung disease among the older population. The findings were robust to the inclusion of controls in the statistical model for other relevant factors such as gender, age, education, wealth, smoking history, circumstances in childhood and housing quality. While effects on all-cause mortality were not yet apparent, further waves of data will be required to assess the longer-run impacts of the ban on population health.

Dublin city was the first area of the country to become subject to a smoky coal ban, with a ban on the sale of smoky coal introduced in 1990. An analysis of the environmental and health effects of the ban showed that it led to large reductions in air pollution and in mortality from respiratory and circulatory diseases (Clancy *et al.*, 2002). In more recent years, there has been a discussion about whether there is any "safe" level of air pollution, and in 2021 WHO revised downwards its air quality guidelines (AQGs) substantially (WHO, 2021). As a result, in Ireland in 2021, average levels of $PM_{2.5}$ were above the new annual WHO AQG value at 65 monitoring stations, and above the daily WHO AQG value at 65 stations (measured at 81 stations in total) (EPA, 2022). Poor air quality is therefore still a significant threat to population health in many towns across the country. From October 2022, new national standards on the sale and use of solid fuels came into effect, effectively banning the sale and use of smoky coal across the country. It will be important to monitor the implementation and effect of the new regulations on population health in the years ahead.

This paper has been published in a peer-reviewed journal (Lyons *et al.*, 2023).

2.3 Long-term Exposure to $PM_{2.5}$ Air Pollution and Mental Health

The research described in this section was carried out by Philip Carthy (University College Dublin), Míde Griffin, Seán Lyons, Anne Nolan and Brian O'Connell (Trinity College Dublin).

2.3.1 Background

Exposure to air polluted with $PM_{2.5}$ is a leading cause of death globally, contributing to both acute illness (particularly affecting the cardiovascular and respiratory systems) and chronic illness throughout the body (Schraufnagel *et al.*, 2019). While the bulk of past research focuses on the effects of $PM_{2.5}$ on physical health, some recent research has also found evidence of associations between exposure to ambient $PM_{2.5}$ air pollution and poor mental health (e.g. Ren *et al.*, 2019; Braithwaite *et al.*, 2019; Gładka *et al.*, 2021; Hao *et al.*, 2022). The present study seeks to add to this literature.

Most research into links between mental health and air pollution has used data on relatively short-term exposures. For example, a recent systematic review found 25 qualifying studies on this topic, but only five of these examined long-term exposures (defined as lasting over 6 months) (Braithwaite *et al.*, 2019). However, some hypothesised that channels through which $PM_{2.5}$ might affect mental health are likely to operate over a longer period, e.g.:

- inflammation affecting the central nervous system;
- changes in stress responsivity;
- adverse effects on cognitive development and dementia risk (Braithwaite *et al.*, 2019).

Focusing exclusively on short-term pollution exposures might miss or understate the impact of longer-term processes. In the present study, we have access to long-term residential histories for a large representative sample of people aged over 50 in Ireland. Using the most recent 17 years from these histories, we can link data on each respondent's mental health status and socio-economic characteristics to spatially coded estimates of annual average $PM_{2.5}$ concentrations in the areas where respondents lived. Since the available data are at the individual level, we can also allow for a wide range of possible confounding socio-economic factors and test for variations in effects across subgroups within the population.

2.3.2 Data and methods

Data on mental health status and socio-economic characteristics

Our core dataset, drawn from TILDA, contains individual-level data on a large nationally representative sample of older adults in Ireland. Three broad types of data/indicators are used in this research:

- indicators of mental health and wellbeing, including scores from questionnaires designed to measure depressive symptoms, anxiety, worry, stress and quality of life; for the present study, these indicators were "Z-standardised" to allow them to be compared on a common scale;[2]
- detailed socio-economic information including age, sex, marital status, long-term disability, employment status, free healthcare eligibility, medication use and an indicator of problems with alcohol;
- residential address history.

2 This involves dividing each score's deviation from the sample mean by the sample standard deviation.

At baseline (2010), there were 8504 over 50s (and partners of any age) in the study. Further waves of data were collected in 2012, 2014, 2016, 2018 and 2021. A key element for the present study is that the third wave (2014–15) of TILDA collected lifetime residential address histories. These histories have been geocoded, permitting the TILDA records to be linked to estimates of local air pollution for each year and residential location covering the period 1998–2014. After attrition and linkage, 3407 observations of the full set of variables were available.

Data on air pollution concentrations at residential addresses

We drew on global estimates of annual average $PM_{2.5}$ concentrations at 0.01 degree resolution (approximately a 1 km grid) between 1998 and 2014. These data were downloaded from Hammer *et al.* (2022) and are described in Hammer *et al.* (2020). In essence, satellite sensors measure particulates blocking various wavelengths of light in a column of air. The concentration of $PM_{2.5}$ air pollution in each grid cell across the world is modelled by calibrating the sensors' readings to reflect direct ground-based estimates in places where measurements are available and applying an atmospheric chemical transport model. In the present study, we mapped the projected pollutant concentrations to residential addresses in Ireland, providing a proxy for local pollution exposures.

Broad patterns in the data are illustrated in Figure 2.2, which shows $PM_{2.5}$ concentrations at the start and end of the study period. Air pollution estimates are generally higher in the east of Ireland where population density and economic activity are more concentrated. The largest cities experience the highest levels of pollution. Over time, average concentrations have fallen across all areas of Ireland.

Methods

We used ordinary least squares (OLS) regression analysis to explore the relationship between long-term residential $PM_{2.5}$ exposure and a range of mental health and wellbeing metrics. In each model, the *Z*-standardised indicator of mental health is the dependent variable and a range of socio-economic controls are included alongside the $PM_{2.5}$ exposure independent variable.

2.3.3 Results

We found statistically significant positive associations between the 17-year average ambient $PM_{2.5}$ concentration at a respondent's residence and their risk of both depressive symptoms and anxiety (see Table 2.2). The implied scale of effects is large: moving from the reference category to the highest level of exposure in our sample (i.e. from 7 to 12 μg/m^3) implies an increase in depression score of 16.2% of a standard deviation.

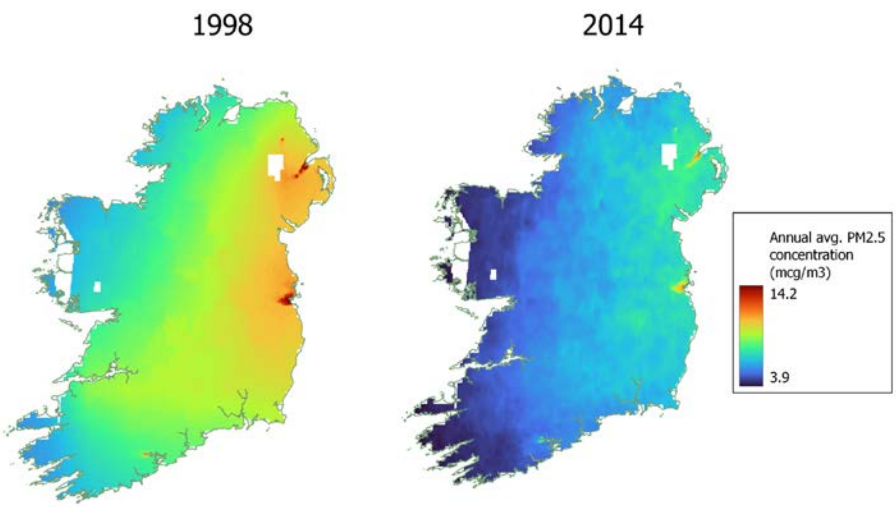

Figure 2.2. Estimated annual average local $PM_{2.5}$ concentrations in Ireland, 1998 and 2014. Source: authors' analysis of data in Hammer *et al*. (2022).

Table 2.2. Summary of linear coefficients for $PM_{2.5}$ exposure (µg/m³) in models of standardised mental health scales with full set of controls, *n* = 3407

Outcome	Coefficient	95% confidence interval		*p*-value
		Low bound	High bound	
Depressive symptoms scale: CES-D	0.0323	0.0103	0.0543	0.004
Anxiety scale: HADS-A	0.0386	0.0163	0.0606	0.001
Penn State Worry Questionnaire scale	–0.0145	–0.0363	0.0073	0.191
Perceived Stress Scale: PSS	0.0000	–0.0225	0.0225	0.999
Quality of Life Scale: CASP-19	0.0134	–0.0086	0.0355	0.231

To further explore the relationships between $PM_{2.5}$ exposure and the indicators of depressive symptoms and anxiety, we re-estimated the models using categories of $PM_{2.5}$ rather than assuming that the relationships are linear. The pollution coefficients are illustrated for both models in Figure 2.3.

These findings reinforce the impression that higher $PM_{2.5}$ exposure is associated with a higher risk of depressive symptoms and anxiety. Indeed, in the case of depressive symptoms, the relationship appears strikingly linear, at least above the reference category of 7 µg/m³.

2.3.4 *Conclusions and policy implications*

These results are consistent with the literature suggesting that people exposed to higher levels of pollution over a long period may experience negative mental health outcomes. However, there are several limitations to bear in mind. There may be important variables omitted from the dataset and correlated with $PM_{2.5}$ exposure, such as exposure to other air pollutants or noise pollution, that could change the scale or significance of the results. It may be more appropriate to see the effects reported here as associated with pollution more broadly, rather than simply as effects of exposure to $PM_{2.5}$ per se. In addition, residents with a particular sensitivity to air pollution may choose to live in areas with the lowest concentrations. This type of sample selection could also affect our results. As a consequence, we cannot conclude that the associations shown in these models are causal.

Looking forward, more granular and locally calibrated measures of pollution would be preferable, although the method used here does have the advantage that it could be applied anywhere in the world. Lastly, we lack pollution measurements from the years when the people in the study sample were children. This would be of particular interest for testing whether harms from pollution are dependent on age of exposure.

A draft of this paper has been completed and is currently being finalised for submission to a peer-reviewed journal.

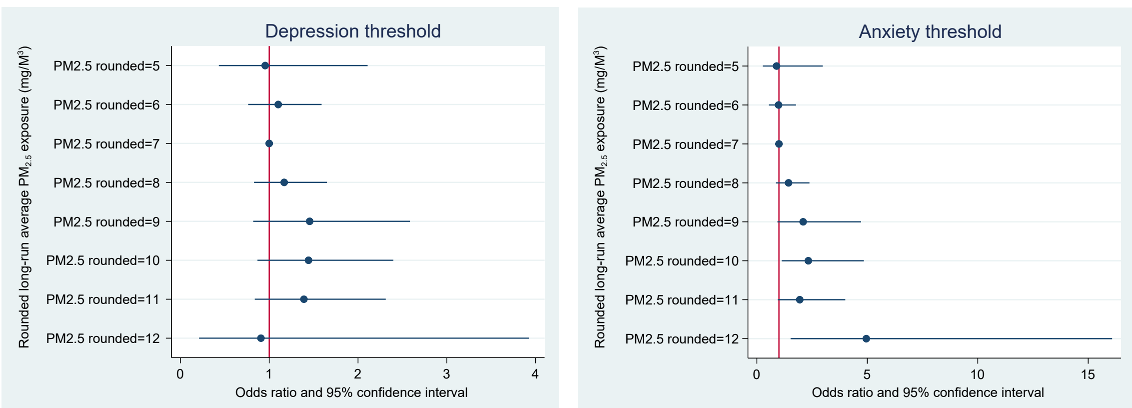

Figure 2.3. Coefficients for rounded $PM_{2.5}$ exposure categories in fully adjusted OLS models of standardised scores for depressive symptoms and anxiety; reference category = 7 µg/m³.

2.4 Solid Fuel Heating Use and Health Outcomes

The research described in this section was carried out by Bertrand Maître and Aidan Sloyan.

2.4.1 Background

Ireland is unusual in a European context in that a considerable proportion of households continues to use solid fuels such as peat, coal and wood for home heating. With almost 18% of homes heated by solid fuels in 2020, Ireland has the second highest use of solid fuels for home heating in Europe, and this figure increases to 62% when secondary heating sources are included.[3] Ireland's high levels of solid fuel use are noteworthy because burning solid fuels is a significant source of carbon emissions, and PM pollution is associated with strong negative health effects. Solid fuels generally have higher emission factors than oil or natural gas and thus contribute disproportionately to residential CO_2 emissions. In addition, solid fuel burning is the predominant source of PM pollution in rural and urban residential areas of Ireland (Wenger *et al*., 2020), and it is estimated that there are around 1300 premature deaths in Ireland every year linked with $PM_{2.5}$ pollution (EPA, 2022). It is clear, therefore, that reducing households' consumption of solid fuels has the potential to improve health and environmental outcomes. This research explores three key research questions:

1. How prevalent are solid fuels as a primary home heating source for Irish households?
2. What characteristics of dwellings and occupants are associated with higher use of solid fuel for residential central heating?
3. What is the health impact of solid fuel heating on dwelling occupants aged 50+?

2.4.2 Data and methods

This study uses two sources of microdata. First, the Household Budget Survey (HBS), carried out by the Central Statistics Office (CSO), is used to explore the demographic, socio-economic and dwelling characteristics associated with solid fuel use for residential heating in Ireland.[4] Second, the TILDA panel data are used to analyse the health impacts of residential solid fuel heating on the population aged 50 and over between 2012 and 2016.

TILDA data use the WHO International Statistical Classification of Diseases and Related Health Problems (ICD-10-AM) to code incident cases of new conditions from one wave to the next (between wave 2 and wave 4 here). This study focuses on different health conditions associated with air pollution that are classified as either circulatory or respiratory diseases. Circulatory diseases comprise various heart conditions, such as heart attack and congestive heart failure, and other conditions such as high blood pressure, stroke and varicose ulcers. Respiratory diseases include asthma and chronic lung diseases such as chronic bronchitis.

2.4.3 Results

Using the HBS data for 2015/16 a multinomial logistic regression model was estimated with three outcomes regarding households' central heating method: no full central heating; solid fuel central heating; and "other" – which comprises oil, gas, electric and geothermal central heating. The model analysed the relationship between central heating type and occupant and dwelling characteristics and location. Regarding the dwelling characteristics, we considered four different dwelling attributes: period of construction, location, tenure and number of bedrooms.

The modelling results showed that dwellings built before 1960 were three times more likely to have no central heating than oil, gas, electric or geothermal heating than those built since 2001. Older buildings were also more likely to use solid fuels, with dwellings built before 2001 being 2–2.5 times more likely to use solid fuels than other heating types than those built after 2000. The location of the dwellings was also strongly linked with heating type. Dwellings located in

3 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_consumption_in_households#Energy_products_used_in_the_residential_sector (accessed 15 August 2023).

4 A recent EPA-funded study, "Residential Fuel Use in Ireland and the Transition Away from Solid Fuels", used data from a new survey of nearly 2000 households to examine residential solid fuel use for both primary and secondary heating, and the role of non-traded solid fuels in residential use (Eakins *et al*., 2022).

the South-West, South-East, Mid-West and Mid-East regions (excluding Dublin) were 11 times more likely to use solid fuels than other types of heating than those in Dublin. Dwellings in the Border, Midland and Western (BMW) region were 38 times more likely to use solid fuels than other types of heating than households located in Dublin. This reflects both the high levels of solid fuel use in the BMW region and the high proportion of households using other types of heating system (particularly natural gas) in Dublin.

The results showed that marital status, education level and social group played a significant role in the central heating method used in the dwellings. Compared with the reference category (oil/gas/electric/geothermal central heating), households where the household reference person (HRP) was married were 1.5 times more likely to use solid fuel heating than households with a divorced/separated/widowed HRP. Households where the HRP had completed primary, secondary or no formal education were 1.5–2 times more likely to use solid fuel than other types of heating than those who had completed higher/third-level education. Households headed by HRPs in non-professional social groups (excluding agricultural workers) were 2–2.5 times more likely to use solid fuel than other types of heating than households headed by higher-level professional HRPs.

In the second part of the analysis, we used TILDA data to explore the relationship between the use of solid fuels for residential heating and health outcomes. The classification of residential heating method was slightly different from that used in the HBS. Respondents were classified into three groups: central heating or portable heater (PH) only; solid fuel appliance (+PH); and closed solid fuel appliance (+PH). We estimated logit models for whether individuals in wave 4 had suffered from a new case of a respiratory or circulatory disease between 2012 and 2016 (waves 2–4). In model 1, with no socio-demographic controls (see Table 2.3), having an open fire was associated with a significant increase in the likelihood of respiratory disease compared with the reference category of individuals with central heating or PH only. Indeed, these individuals were almost 1.7 times more likely to have developed a respiratory disease over time than the reference category. However, once we control for socio-demographic factors and smoking behaviour in model 2, the odds ratio for having an open fire is not statistically significantly different from 1. This suggests that domestic heating source is not significantly related

Table 2.3. Odds ratios for respiratory disease by heating type and other factors

Heating method or other factor		Model 1	Model 2
Primary heating method (ref. central heating/PH only)	Open fire (+PH)	1.684*	1.406
	Closed solid fuel (+PH)	1.049	0.949
Age (years)			1.016
Marital status (ref. not married)	Married		1.001
Sex (ref. female)	Male		0.754*
Education (ref. higher/third-level)	Primary/none		1.250
	Secondary		0.874
Employment status (ref. employed)	Retired		0.967
	Other		1.146
Household income (€) (ref. €80,000+)	Less than 19,999		1.469
	20,000–39,999		1.178
	40,000–59,999		1.287
	60,000–79,999		1.346
Cigarettes per day (ref. non-smoker)	Fewer than 10		1.365
	10–19		1.717*
	20+		2.258**

The data presented are based on 3986 observations.

**** and * correspond to significance at the 5% and 10% level, respectively.**

Ref., reference category.

to respiratory disease morbidity once we consider other individual-level characteristics. Holding all else equal, men were less likely to report that they suffered from a respiratory disease than women, although this odds ratio is only marginally significant at the 5% level. As expected, the number of cigarettes consumed per day is associated with increased respiratory disease morbidity.

A similar analysis with the same explanatory variables was also used to examine the relationship between the use of solid fuels and developing a circulatory disease over time. Without controlling for socio-demographic variables and smoking behaviour, we found that individuals with an open fire had an increased likelihood of circulatory disease of around 1.3 times that of individuals with central heating or portable heaters. However, adding controls for socio-demographic factors and smoking behaviours, there were no significant differences in the likelihood of circulatory disease between individuals with an open fire and individuals with central heating or portable heaters, mirroring our finding for respiratory disease. In terms of personal characteristics, being older, male and not in employment (retired or other) were all found to significantly increase the likelihood of circulatory disease.

2.4.4 Conclusions and policy implications

Reducing the use of solid fuels for home heating has the potential to yield substantial environmental and health benefits. This paper contributes to the existing literature on the use of solid fuels by analysing the attributes of dwellings and occupants that are using solid fuels for central heating in Ireland, as well as looking at the health impact of burning solid fuels on people aged 50 and over. The analysis found that both dwelling characteristics and occupants' attributes are significantly related to solid fuel use. Households located outside Dublin are more than 10 times as likely to use solid fuel than oil, gas, electric or geothermal heating than Dublin-based households – and the likelihood is even greater for households located in the BMW region. Older dwellings, particularly those built before 1960, are more likely to use solid fuel for central heating. This indicates that targeted support for transitioning to oil, gas, electric or geothermal heating aimed at people living in older dwellings and in certain locations could be effective in reducing the use of solid fuels for domestic heating.

In terms of occupant characteristics, the marital status, education level and social group of the HRP are all significantly associated with solid fuel use. These findings suggest that there is potential for policies to target certain groups to effectively promote fuel switching.

Lastly, our analysis showed that open fire use is correlated with higher incidences of respiratory and circulatory disease. Surprisingly, we found that the link between heating type and disease morbidity was not robust following the inclusion of controls for socio-demographic characteristics and smoking behaviour. However, this analysis focused only on incident cases of respiratory and circulatory disease; as further waves of TILDA data become available, additional analysis can examine the link between changes in residential fuel heating type and disease morbidity.

A draft of this paper has been completed and is currently being finalised for submission to a peer-reviewed journal.

2.5 Drinking Water Quality and Healthcare Utilisation of Older People

The research described in this section was carried out by Gretta Mohan and Seán Lyons.

2.5.1 Background

Morbidity and mortality linked to waterborne diseases are expected to rise in many jurisdictions as climate change increases the risks of infection of these diseases and populations in developed countries tend to grow older. In this research, we examined whether use of healthcare services is higher among older people in areas where *Escherichia coli*, a disease-causing pathogen, was detected in drinking water tests.

2.5.2 Data and methods

Using a novel data-linking approach, we linked three sources of data to conduct the analysis. Administrative records of *E. coli* detection, recorded from routine water quality tests carried out by the EPA, were first linked to maps of the water systems infrastructure in Ireland. Then these data were linked to information on the healthcare use and other characteristics of participants in TILDA, a nationally representative survey of over 50s in Ireland.

Three types of healthcare use were examined: visits to general practitioner (GP) services, emergency department (ED) attendances and nights spent in hospital. We used statistical methods to test whether healthcare use was higher among study participants in areas where *E. coli* was detected than in other areas. Influences on individuals' healthcare utilisation, such as gender, age, marital status, educational attainment, employment status, medical card status, private health insurance, indicators of physical and mental health and health behaviours, were also taken into account.

2.5.3 Results

Relatively few residences (4%) were connected to water supplies in which *E. coli* was detected. Figure 2.4 shows that the mean number of GP visits made by those for whom *E. coli* was detected in the water supply was slightly higher than for those for whom this was not an issue, and this pattern was replicated for the mean number of ED visits and hospital nights. The results from statistical modelling indicate that the presence of *E. coli* in monitored water supplies is associated with higher demand for GP services and hospital nights.

2.5.4 Conclusions and policy implications

This research suggests a link between water quality and the burden on healthcare services among older people, in which a greater risk of GP visits and hospital nights was associated with the presence of *E. coli* in residential water supplies. This evidence can be used to support the case for intervention and action to improve the quality, treatment and monitoring of drinking water in Ireland. The findings may be of interest to environmental and healthcare planners, the farming community, water officials and public health professionals, including the Medical Officer of Health, who is legally responsible for the investigation and removal of sources of infectious diseases, in compliance with the Infectious Diseases Regulations. Considering the significant threat of climate change, there is an enhanced requirement for co-operation among all relevant agents to reduce or eliminate the health hazards presented by water contamination. Satellite surveillance data for weather and climate forecasting may become an essential early warning system for water-related diseases and healthcare use.

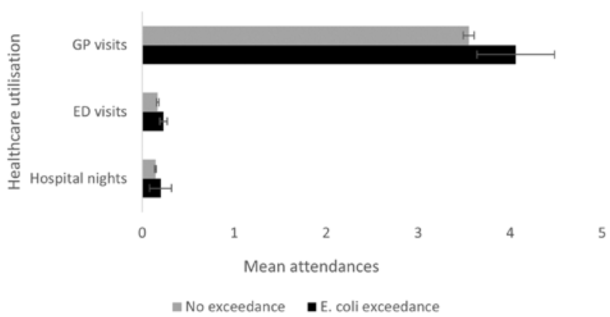

Figure 2.4. Use of healthcare services by *E. coli* exceedance during preceding year at respondent's residence. Source: reproduced from Mohan and Lyons (2022); licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

These findings underline the need to protect the quality of drinking water, thereby improving public health and reducing the burden on healthcare services. This is all the more important in the face of increasing global temperatures, which present greater risks of water contamination, in combination with the ageing of developed societies. Further academic study is required to build a better picture of the contribution of drinking water supplies, both publicly regulated sources and private unregulated sources, to illness and the consequences and costs of this to societies in the 21st century.

This paper has been published in a peer-reviewed journal (Mohan and Lyons, 2022), and an accompanying non-technical research bulletin is also available at: https://www.esri.ie/system/files/publications/RB202215_1.pdf

2.6 Healthcare Costs of Water-related Diseases

The research described in this section was carried out by Míde Griffin and Brendan Walsh.

2.6.1 Background

Exposure to environmental pollutants and water-related diseases (WRDs) can result in negative health outcomes for affected individuals and populations. While for many people illness caused by WRDs may result in only a minor short-term inconvenience, more severe outcomes such as hospital admission may occur, potentially increasing healthcare costs. Across European countries, Ireland has among the highest rates of microbial contamination in drinking water. A number of high-profile outbreaks of disease caused by *Cryptosporidium*, *Campylobacter* and verotoxigenic *E. coli* (VTEC) have occurred as a result of such contamination. However, no study has examined the impact of WRDs on healthcare use at a national level and the healthcare costs that may be attributable to WRDs in Ireland.

The literature on WRD healthcare costs concentrates on regional water pollutant outbreaks. A large cryptosporidiosis outbreak that occurred in the west of Ireland in 2007 is estimated to have cost, at a societal level, €19 m in total. Of these total costs, healthcare costs of €650,000 were estimated, with the majority (€637,000) attributed to hospital care (Chyzheuskaya *et al*., 2017). Similar findings from localised WRD outbreaks have been found in Sweden and Finland (Huovinen *et al*., 2013; Larsson *et al.,* 2014). Across all studies, the majority of the healthcare costs were due to the excess hospitalisation of people with severe reactions from the WRD. However, as the literature on WRD-related healthcare costs focuses on specific localised outbreaks, it is difficult to understand the true healthcare costs of WRDs. Identified outbreaks may capture only a small proportion of all WRD-related healthcare costs, and smaller but more numerous outbreaks can go undetected as public health practices and water quality measurements may be lacking. The use of retrospective questionnaires may also fail to capture a large proportion of costs. This study circumvents these issues by using detailed resource-costed administrative data on hospital admissions at a national level, with diagnostic coding data accurately identifying WRD-related hospitalisations.

2.6.2 Data and methods

This study was a retrospective, cross-sectional study of WRDs in Irish public hospitals using the HIPE dataset (2015–2018). HIPE is a routinely collected administrative dataset capturing all public hospital discharges. It includes a range of patient-level demographic information and admission information including principal and secondary diagnoses using the ICD-10-AM. The WHO classification was used to determine whether the discharge was WRD related.

Study sample

HIPE cannot determine whether a hospitalisation was explicitly due to water pollutants. However, the ICD-10-AM codes can identify patients with diagnoses likely to be caused by a WRD. We used a broad WRD definition to ensure the inclusion of all potential WRD-related hospitalisations using information on the probability that a disease is due to a water pollutant outbreak in northern Europe (Global Infectious Disease and Epidemiology Online Network (GIDEON) data). We then estimated lower and upper bounds surrounding these cost estimates based on the probability that the hospitalisation was related to a WRD: probability calculated as 1 ± (percentage of disease outbreaks linked to water pollutants)/2.

Diagnoses were ranked into three specific groups according to WRD probability and number of diagnoses. We define our “main” WRD group, group 1, as patients with a primary diagnosis of cryptosporidiosis, campylobacteriosis, giardiasis, and infection with rotavirus or VTEC. Group 2 includes patients with unspecified gastroenteritis. Group 3 includes less common WRD diagnoses such as hepatitis A and adenovirus infection. Diagnoses with fewer than 30 hospitalisations were excluded.

As hospital admissions for a WRD are unscheduled, we included only emergency inpatients who attended one of the large adult or children’s hospitals in Ireland with a 24-hour ED.

Methodology

Descriptive and multivariate regression analyses were undertaken. Two variables were used to examine hospital resource use: costs apportioned to diagnosis-related groups and length of stay (LOS). We first estimated the cost of WRD-related hospitalisations using the costs apportioned to each patient in HIPE. Second, we examined LOS across patient characteristics. Third, as evidence shows seasonal and spatial variation in WRDs, we examined whether there are disproportionate WRD-related hospitalisations in specific age groups, hospitals and times of year.

Costs

The costs included in this study are based on activity-based funding (ABF) and reflect the resources used to care for a patient. This is the mechanism used within hospital systems to allocate resources and allows budgets to be accurately aligned with the activities hospitals carry out. ABF includes all the costs of care (equipment, staff pay and overheads). These costs take into account the complexity of care provided and the patient case mix, ensuring, for example, that patients with a longer hospital stay carry greater weight when determining the resources they consume. As all emergency inpatients will have been processed via an ED, and thereby incur costs in the ED, we apportioned €298 per ED attendance to all hospitalisations.

Length of stay

This study uses LOS (the time, in days, from inpatient admission to discharge) to examine resource use differences across patient groups. Linear regressions include LOS in its natural logarithmic form to examine the impact of explanatory variables on average LOS for WRD-related hospitalisations. Regression analyses control for pertinent factors including day of discharge, discharge month and year, age, weighted Charlson comorbidity score (a measure of illness), public or private healthcare status and sex. Hospital fixed effects are included to control for unobserved hospital-level heterogeneity, and standard errors are clustered at the hospital level.

2.6.3 Results

From 2015 to 2018 there were over 41,500 WRD-related hospitalisations. We estimate WRD-related total costs of €8.2 m–€24.6 m (Table 2.4).

Table 2.4. Water-related disease hospitalisation costs in Ireland, 2015–2018

ICD-10 diagnosis	Costs (€, lower bound)	Costs (€, upper bound)
Group 1	2,649,690	7,949,070
Group 2	5,193,375	15,580,125
Group 3	371,248	1,113,745
Total	8,214,313	24,642,939

Approximately 33% of all costs occurred in Group 1 (€2.7 m–€7.9 m). Between €5.2 m and €15.6 m of costs were a result of unspecified gastroenteritis (Group 2) caused by water pollutants. Group 3 diagnoses contributed only a small amount to hospital costs, due to a combination of low hospitalisations and the low likelihood of the hospitalisation being caused by a water pollutant.

Regression results find that LOS was 25% longer for group 1 than for group 2, and 33% longer for group 1 than for group 3. Female patients, patients with more comorbidities (higher Charlson score) and older patients had longer hospital stays. Patients treated as public patients had shorter hospital stays. Figure 2.5 shows that LOS was much higher in group 1 than in other groups for those with low Charlson scores. LOS was much higher in group 1 among younger patients, but no differences across WRD groups were seen among older patients. These results suggest that the longer hospital stay for group 1 WRD patients was driven predominantly by children with low (or no) comorbidities. For older or sicker groups, LOS tends to be longer regardless of the type of WRD diagnosed.

Figure 2.6 highlights that group 1 WRD-related hospitalisations are disproportionately dispersed and mainly consigned to a small number of hospitals. Five out of 29 hospitals account for over 30% of such hospitalisations. These hospitals are either outside Dublin with large rural catchments or Dublin-based children's hospitals. WRD-related hospitalisations are also disproportionately seen in January–March and April–June. This agrees with previous literature showing a clear seasonality in the prevalence of WRDs.

2.6.4 Conclusions and policy implications

Despite Ireland having among the highest rates of WRDs in Europe, the burden placed by these diseases on hospitals is moderate. This study estimates that the hospital costs of WRDs between 2015 and 2018 was at most €24.6 m. However, WRD-related hospitalisations disproportionately affect specific groups. Controlling for patient demographics, patients infected with rotavirus, *Campylobacter*, *Cryptosporidium* and VTEC had significantly longer hospital stays than other WRD groups of patients. Delving into this longer hospital stay, we found that

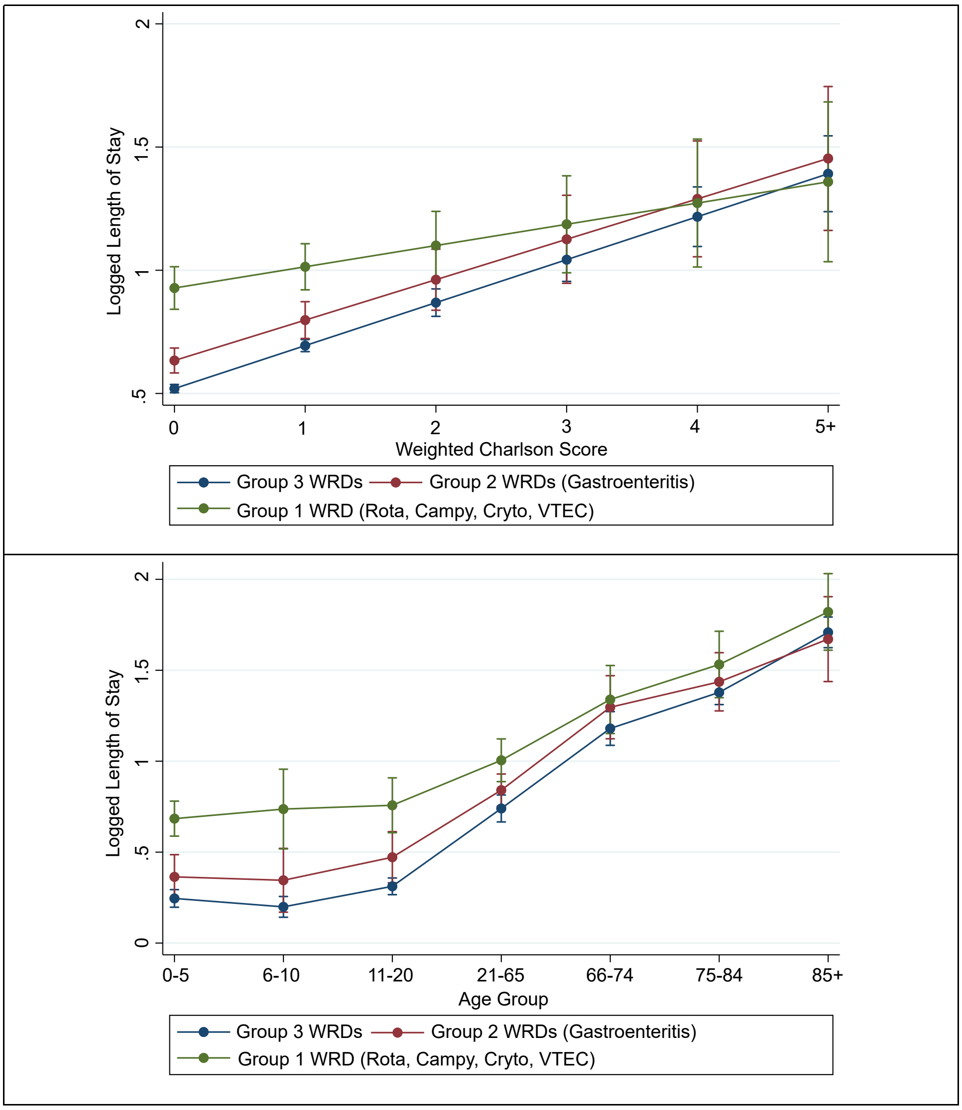

Figure 2.5. Determinants of length of water-related disease hospitalisation in Ireland: comorbidity (top) and age (bottom).

these differences were driven by younger patients with little or no comorbidity. This result highlights that, while the total burden of these WRDs was low, patients admitted to hospital for WRDs were treated as complex cases and therefore incurred large average costs. Furthermore, it was clear that hospitals with rural catchments were disproportionately affected by WRD-related hospitalisations.

Similar to previous findings in the literature, we find that the costs incurred by the health system for treating WRDs are relatively low. However, the burden can be high, disproportionately affecting younger people and a small number of rural or children's hospitals during the spring and summer months. This finding in particular will allow limited public health resources to target specific regions at certain times of the year to further reduce outbreaks of WRDs. Environmental policies that aim to improve water quality and reduce the public health impacts of water pollution could target specific areas at specific times. Rural areas with high proportions of the population using private water sources could be good targets for well testing during the spring.

A draft of this paper has been finalised and submitted to a peer-reviewed journal.

hospital	Area	2015Q1	2015Q2	2015Q3	2015Q4	2016Q1	2016Q2	2016Q3	2016Q4	2017Q1	2017Q2	2017Q3	2017Q4	2018Q1	2018Q2	2018Q3	2018Q4	Hospital%
H1	Non-Dublin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0%
H2	Dublin Area	0	1	1	1	0	0	1	0	1	2	1	0	0	0	2	2	0.3%
H3	Non-Dublin	0	1	2	2	1	1	1	1	2	1	1	2	0	1	0	0	0.3%
H4	Dublin Area	1	2	4	2	4	1	2	0	0	1	9	1	0	3	4	2	0.8%
H5	Dublin Area	1	0	4	3	0	4	4	2	2	2	3	4	1	5	2	1	0.8%
H6	Dublin Area	2	1	1	3	3	4	0	5	4	3	4	4	3	2	2	0	0.9%
H7	Dublin Area	0	4	5	7	2	1	2	4	3	4	3	4	5	7	9	9	1.4%
H8	Dublin Area	0	2	1	4	2	3	4	5	7	7	9	8	5	5	6	7	1.6%
H9	Dublin Area	6	5	5	5	4	9	13	3	6	4	5	0	4	5	5	5	1.8%
H10	Non-Dublin	7	19	8	3	1	8	3	6	4	26	3	4	0	5	7	0	2.2%
H11	Non-Dublin	10	11	1	2	2	11	3	9	5	18	12	8	4	8	0	4	2.3%
H12	Non-Dublin	26	21	4	1	4	29	6	2	7	19	3	0	5	7	1	0	2.8%
H13	Non-Dublin	20	31	5	0	6	7	5	4	28	17	6	3	1	12	1	2	3.1%
H14	Non-Dublin	15	17	6	6	10	30	8	3	22	23	2	3	5	6	6	4	3.5%
H15	Non-Dublin	14	31	12	4	4	23	6	9	23	15	5	3	5	17	4	0	3.7%
H16	Childrens	41	52	4	1	10	17	5	2	18	23	4	5	7	4	15	4	4.4%
H17	Non-Dublin	11	14	4	3	10	23	9	8	27	36	9	4	6	23	9	16	4.4%
H18	Non-Dublin	37	20	9	5	7	33	15	8	13	33	6	3	4	11	13	3	4.6%
H19	Non-Dublin	30	18	9	5	12	32	14	19	17	24	12	4	2	16	14	3	4.8%
H20	Non-Dublin	54	33	5	2	16	28	12	6	16	31	6	7	4	9	3	0	4.8%
H21	Non-Dublin	27	24	10	3	10	32	13	12	19	28	9	8	6	21	5	8	4.9%
H22	Non-Dublin	44	43	6	3	6	35	9	7	16	31	17	5	2	9	9	4	5.1%
H23	Non-Dublin	41	31	13	12	9	23	25	19	10	25	5	7	9	18	10	4	5.4%
H24	Non-Dublin	69	28	8	2	3	28	10	10	16	42	16	7	6	12	7	6	5.6%
H25	Childrens	44	46	10	1	17	37	5	14	30	32	4	5	5	23	7	4	5.9%
H26	Non-Dublin	34	45	13	2	10	40	8	3	19	26	14	5	9	29	20	9	6.0%
H27	Childrens	29	29	15	2	19	49	4	11	35	32	15	10	12	17	3	5	6.0%
H28	Non-Dublin	55	52	15	7	11	26	16	2	24	40	6	8	3	7	10	6	6.0%
H29	Non-Dublin	47	34	14	8	16	36	16	4	21	52	14	8	5	19	15	14	6.7%
		665	615	194	99	199	570	219	178	395	597	203	130	118	301	189	122	1

Figure 2.6. Water-related disease hospitalisations by season and hospital in Ireland.

3 Behavioural Science

The research described in this chapter was carried out by Ylva Andersson, Kieran Mohr, Pete Lunn and Shane Timmons.

3.1 Introduction

The aim of this component of the programme was to employ techniques from behavioural science to design and test regulatory communications for use by the EPA. Building on research carried out in Phases I and II of the programme, the Phase III behavioural science studies examined the design of an alternative radon risk map (section 3.2) and the design of youth communication materials (section 3.3) and effective strategies for communicating with the public on waste management (section 3.4).

3.2 Behavioural Testing of Radon Risk Maps

The research described in this section was carried out by Shane Timmons and Pete Lunn.

3.2.1 Background

Radon exposure in homes is a leading cause of lung cancer (Dempsey *et al*., 2018a), but the rate at which householders test for this environmental risk is low (e.g. Poortinga *et al*., 2011). Our aim was to increase householders' propensity to test for radon, using the methods of behavioural science to test a range of improved communication strategies. Specifically, we sought to experimentally test two approaches that could be enacted at scale: providing the public with general information about radon and enabling individuals to find their personalised risk estimate via a radon hazard map. The logic for these approaches is straightforward: people cannot perceive risk from a hazard they are unaware of, and the more accurately they can estimate their susceptibility to the risk, the better they can make decisions about mitigating it. The nature of these interventions was informed by psychological theory and literature.

3.2.2 Methods

A nationally representative sample of 1700 adults completed an online experiment involving multiple stages. Participants first completed a survey measuring their familiarity with and knowledge of radon. The knowledge questions probed basic factual knowledge of radon (e.g. it is a gas, exposure causes lung cancer) and understanding of testing and remediation. Half of the participants were randomised to see the correct answers to the knowledge questions after attempting to answer the questions themselves. This approach allowed us to assess knowledge in the full sample while experimentally testing the effect of information provision on later responses. Participants then recorded their perception of radon as a risk.

For the main experimental task, participants were randomly assigned to one of 16 experimental maps or a control map (the pre-existing map in use by the EPA; Figure 3.1). The experimental maps varied in four factors: the risk description (numerical frequency or simple categorisation), the number of risk categories (two or three), the colour scheme (yellow to red or yellow to black) and interactivity (either a postcode search with clear county boundaries and extensive zoom functionality or limited zoom functionality with no search function or county boundaries). Hence the design was a 2 × 2 × 2 × 2 between-groups design, making a total of 16 combinations. Figure 3.1 shows two example maps that differ in each factor.

After using the radon hazard map, participants were asked about their perceived risk from radon using the same questions as before. We also measured how likely they would be to test for radon (on a scale from 1 "not at all" to 7 "extremely").

3.2.3 Results

Participants who saw the answers to the knowledge questions perceived greater risk from radon on two of the three measures than those who did not. Ordinal logistic regression models show that they reported being more worried about radon and judged that the

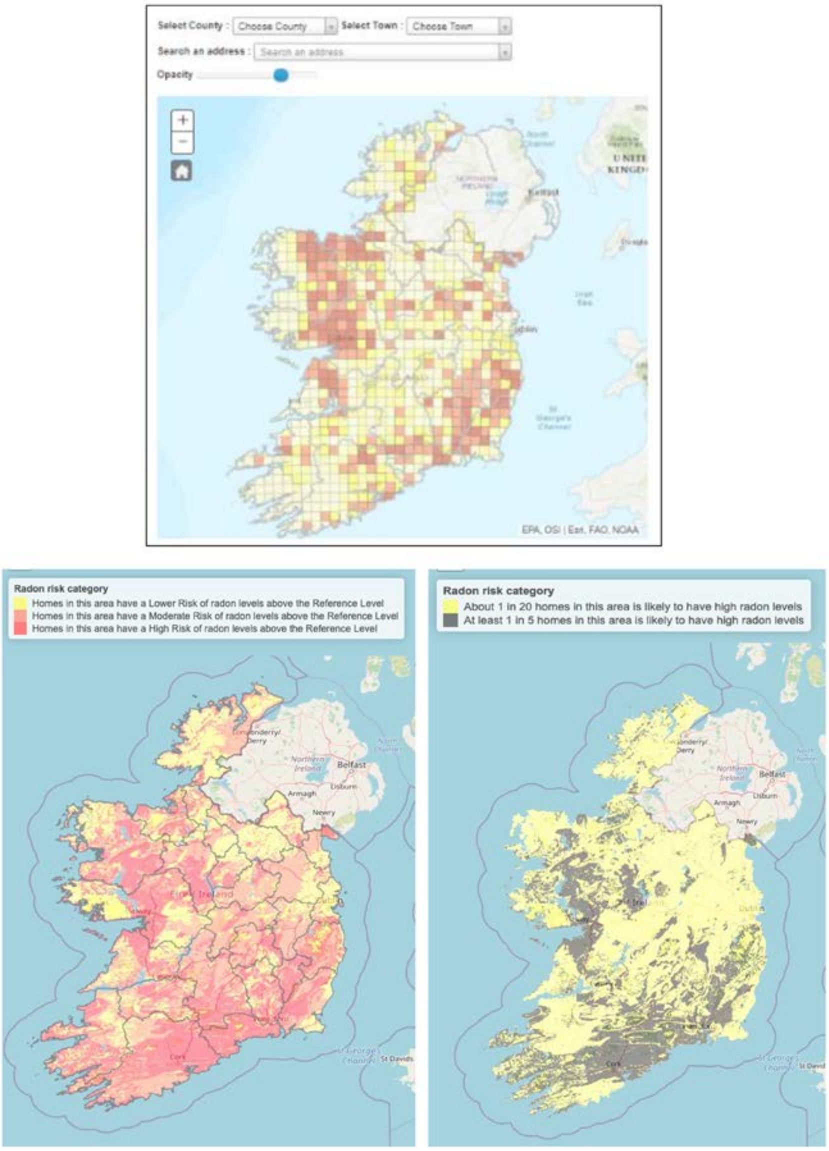

Figure 3.1. Pre-existing radon risk map (top) and example test maps (bottom). The bottom-left map shows a three-category map with search functionality, the yellow to red colour scheme and a legend that uses the simple statement of risk (“lower”, “moderate” or “high”). The bottom-right map shows a two-category map with limited search functionality, the yellow to black colour scheme and a legend that uses a risk frequency statement (e.g. “1 in 5”). Source: reproduced from Timmons and Lunn (2023); licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

effects of radon would be worse for them or someone in their household, even when controlling for how many questions they answered correctly and socio-demographic background characteristics (Table 3.1). They were not more likely to believe that their home would be affected.

We ran ordinal logistic regression models to determine how features of the map influenced the three dimensions of perceived risk after using the map, controlling for socio-demographic characteristics and whether the participant saw the quiz answers before using the map (Table 3.2). Participants reported greater worry after using maps with legends that communicated risk as a numerical frequency rather than a simple statement and after using maps with three categories rather than two (Figure 3.2). There were no differences based on colour or search functionality. The pattern was similar for participants’ belief that their home could be affected by radon, but the effects were stronger (Figure 3.2). Turning to perceived severity of their home being affected by

Table 3.1. Ordinal logistic regression models predicting perceived risk by knowledge intervention

	Worry		Likelihood		Severity	
Variable	Coefficient (95% CI)	*p*-value	Coefficient (95% CI)	*p*-value	Coefficient (95% CI)	*p*-value
Saw answers (ref. no answers)	0.23 (0.06 to 0.40)	0.007	0.13 (–0.04 to 0.05)	0.137	0.29 (0.12 to 0.47)	0.001
Quiz score	0.05 (–0.03 to 0.13)	0.187	–0.02 (–0.11 to 0.05)	0.485	0.21 (0.13 to 0.29)	< 0.001

The data presented are based on responses from 1700 participants. Socio-demographic factors were controlled for in all models.

Ref., reference category.

Table 3.2. Ordinal logistic regression models predicting perceived risk after using test maps

	Worry		Likelihood		Severity	
Variable	Coefficient (95% CI)	*p*-value	Coefficient (95% CI)	*p*-value	Coefficient (95% CI)	*p*-value
Frequency legend (ref. simple)	0.26 (0.08 to 0.43)	< 0.001	0.52 (0.34 to 0.69)	< 0.001	–0.05 (–0.23 to 0.12)	0.558
Three categories (ref. two)	0.19 (0.02 to 0.37)	0.030	0.31 (0.13 to 0.48)	0.001	–0.14 (–0.32 to 0.03)	0.111
Colour: black (ref. red)	–0.08 (–0.25 to 0.10)	0.379	–0.06 (–0.24 to 0.11)	0.481	–0.08 (–0.26 to 0.09)	0.347
Search functionality (ref. limited)	0.01 (–0.17 to 0.18)	0.939	–0.06 (–0.24 to 0.11)	0.486	0.04 (–0.13 to 0.22)	0.642
Saw answers (ref. no answers)	0.11 (–0.06 to 0.28)	0.211	0.08 (–0.10 to 0.25)	0.390	0.19 (0.01 to 0.36)	0.036

The data presented are based on responses from 1589 participants. Socio-demographic factors were controlled for in all models.

Ref., reference category.

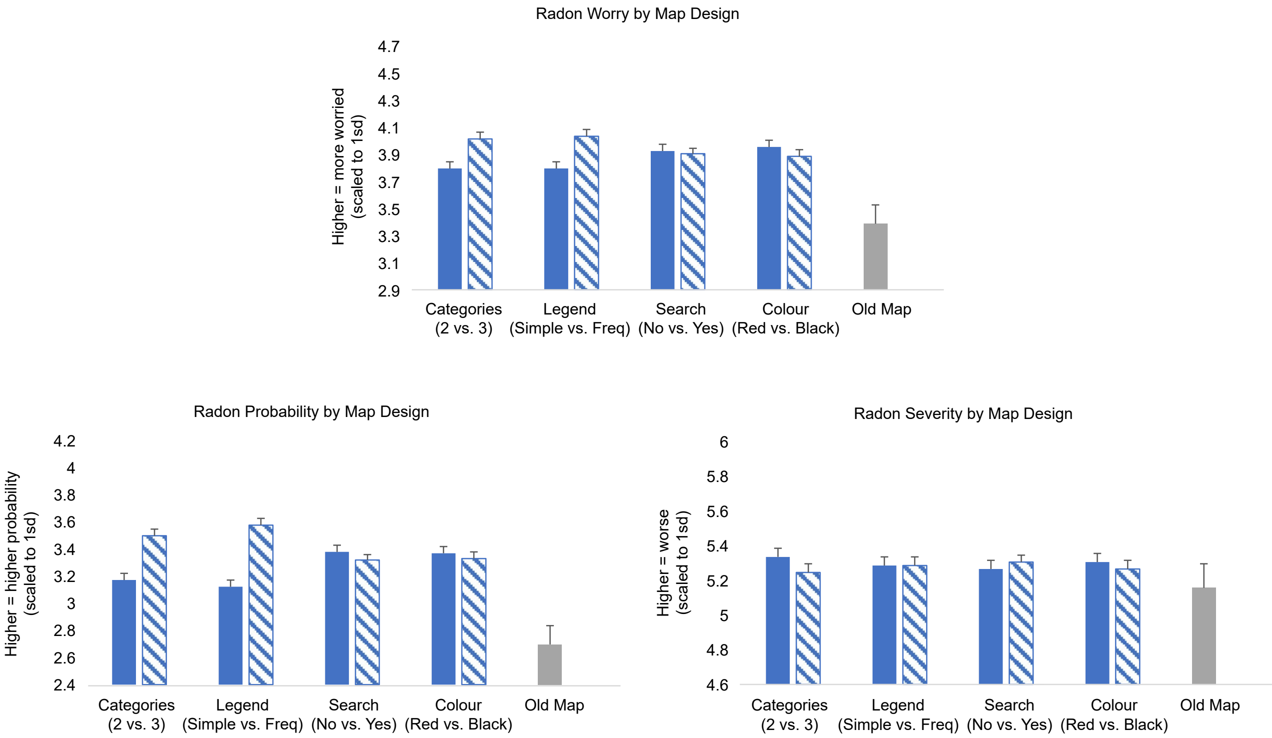

Figure 3.2. Average risk perception ratings after using the radon risk map by map features. Error bars are standard errors. The *y*-axes are scaled to one standard deviation to indicate effect sizes. Source: reproduced from Timmons and Lunn (2023); licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

radon, there were no significant differences between the test maps, although the knowledge intervention did still have an effect.

An ordinal logistic regression for the test maps, controlling for seeing the quiz answers and the participants' area risk, shows that participants who saw maps with three categories were more willing to test for radon than those who saw maps with two categories, although this effect weakens and is not statistically significant when socio-demographic controls are added to the model (Table 3.3). Participants who read the frequency-based legend rather than the simple statement were more willing to test for radon (M = 4.3 vs 4.1). Participants who saw the highest risk category as black were less willing to test and there was no effect of search functionality on willingness to test. Those who learned that they lived in a high-risk area were more willing to test than those who learned that they lived in a moderate-risk area, who in turn were more willing to test than those who learned that they lived in a low-risk area (M = 5.3 vs 4.7 vs 3.3).

3.2.4 Conclusions and policy implications

The results suggest clear strategies for communicating with the public about radon. Participants who received the correct answers to the quiz perceived the consequences of radon exposure to be worse than those who had not seen the information. The effect persisted after they learned the level of risk in their area. The risk maps that used numerical frequencies (e.g. 1 in 5 houses have high levels of radon) increased participants' levels of worry about radon and perceived likelihood of exposure compared with the maps that used simple statements of risk. Hence, the results imply that perceived risk from radon can be amplified by a strategy that combines providing households with more information about radon and communicating risk statistics using numerical frequencies.

Table 3.3. Regression models predicting willingness to test

	Willingness to test	
Variable	Coefficient (95% CI)	*p*-value
Frequency legend (ref. simple)	0.23 (0.05 to 0.41)	0.010
Three categories (ref. two)	0.13 (–0.05 to 0.31)	0.147
Colour: black (ref. red)	–0.18 (–0.36 to –0.01)	0.037
Search functionality (ref. limited)	0.07 (–0.11 to 0.24)	0.461
Answers (ref. no answers)	0.04 (–0.13 to 0.22)	0.644
Radon risk (ref. lower)		
Moderate	1.19 (0.96 to 1.42)	< 0.001
High	1.92 (1.66 to 2.18)	< 0.001

The data presented are based on responses from 1589 participants. Socio-demographic factors were controlled for in all models.

Ref., reference category.

Numerical frequencies also boosted willingness to test for radon. The size of the effect was not small, particularly when combined with other map features. Compared with the pre-existing map in use by the EPA at the time of the study, 72% more people reported being highly willing to test their home for radon after using a map that communicated risk using numerical frequencies, had three categories of risk, used a typical yellow to red colour scheme and had search functionality. The clear implication of these results is that the pre-existing map should be replaced with one that has these features.

This study presented an initial attempt to encourage householders to test for radon and was limited to assessing intentions. While the direction and magnitude of the effects we observed are encouraging, in particular for the use of numerical frequencies when communicating risk, these findings would ideally be substantiated by experimental trials that assess real behaviour. To address this, a communication-based randomised controlled trial with households at high risk of radon exposure will be undertaken as the next phase of this research.

The findings from this study have informed the design of the radon risk map hosted on the EPA website: https://www.epa.ie/environment-and-you/radon/radon-map/. The full research paper has been published as an ESRI working paper (Timmons and Lunn, 2023).

3.3 Diagnostic Experiment on Household Waste Management

Research described in this section was carried out by Shane Timmons, Kieran Mohr and Pete Lunn.

3.3.1 Background

Around 20% of material in household recycling bins cannot be recycled, reducing the quality and value of the household recycling process. There are multiple potential reasons underlying the mismanagement of household waste, including motivation (Babaei *et al*., 2015), perceived norms (Ek and Söderberg, 2021) and lack of knowledge (Goldenhar and Connell, 1991). Our aim was to conduct a controlled, diagnostic experiment to identify the drivers of household waste mismanagement that may be amenable to intervention in a subsequent randomised controlled trial (RCT).

3.3.2 Methods

A nationally representative sample of 400 adults was recruited by a market research agency to complete a 20-minute online study. The study proceeded over multiple stages and used different types of interactive tasks. Survey scales, ranking tasks and free-text questions were used to measure attitudes to recycling and food waste segregation, including judgements about related activities and individual actions (e.g. washing containers), and perceptions of other people's behaviour. Participants were asked general questions about their knowledge of the recycling process (e.g. how materials are sorted) and about the types of materials that are recyclable (e.g. glass). They also completed "choice tasks" in which they were presented with images of waste and their task was to respond with the most appropriate action for that waste (e.g. if it was suitable for recycling at home; Figure 3.3). We recorded both the accuracy of the answers and the response times for these tasks. Survey questions were used to assess awareness of local facilities (e.g. bring banks) and in-home facilities, as well as participants' self-reported frequency of recycling and food segregation activities.

3.3.3 Results

Given the scope of measures included in the study, we report here only a selection of findings. Participants reported positive overall attitudes to recycling, with 50% giving the maximum positive response (7 out of 7) and 38% giving the next highest response. Attitudes towards segregating food waste were also positive, albeit to a lesser extent (Figure 3.4).

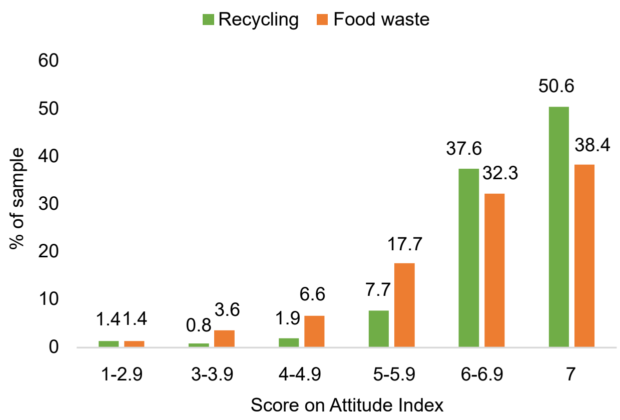

Figure 3.4. Distribution of scores on the attitudes index for recycling and food waste.

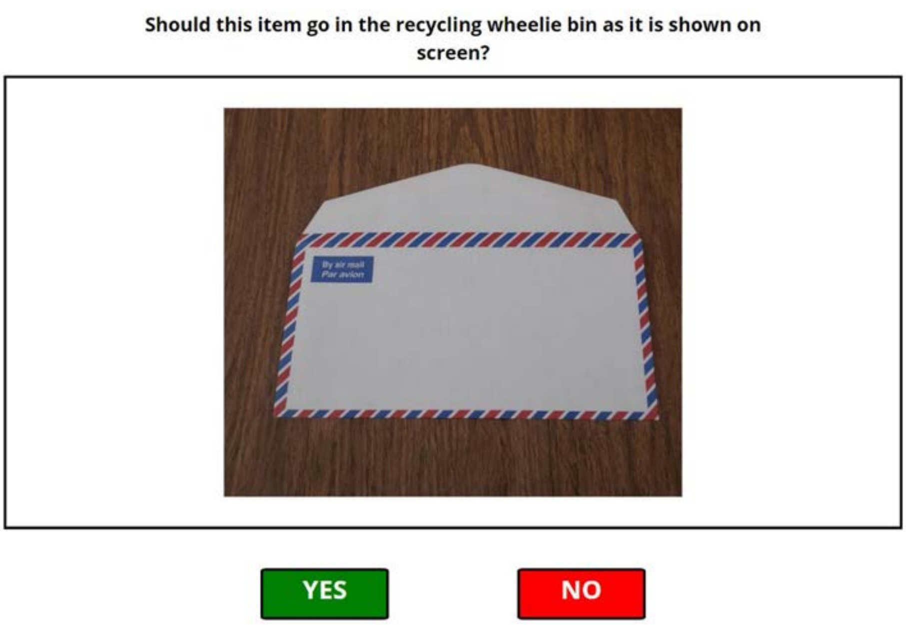

Figure 3.3. Example choice task.

Despite the positivity of attitudes towards recycling, less than half of participants reported usually or always engaging in the behaviours necessary for good household waste management (i.e. washing containers, separating materials; Figure 3.5). In the free-text task, the most frequently mentioned reason for not using a separate food waste bin was hygiene (33% of the sample). Exploratory analyses showed that people who do not have a separate food waste bin judged having one to be less hygienic than those who do have one. This difference may point towards misperceptions of hygiene that are corrected by experience.

Participants were more pessimistic about the behaviour of their neighbours than about their own behaviour. The most typical responses were that participants believed that only about half of their neighbours recycle or manage their household food waste properly (Figure 3.6).

Turning to the choice task, there were some groups of items that participants allocated to the correct waste management approach quickly and some groups that were allocated to the incorrect process after some deliberation (Figure 3.7). Most of the “fast and accurate” items were hard plastics, cardboard, paper and aluminium items. The “slow and inaccurate” items were primarily composites, such as crisp tubes, laminated paper and packaging comprising both cardboard and plastic components. Some soft plastics were quickly allocated to the wrong disposal method (among people who did not realise that soft plastics could be recycled).

3.3.4 Conclusions and policy implications

The findings from this diagnostic experiment show broadly positive attitudes among the public towards proper household waste management. Hence, motivational interventions to reduce cross-contamination are unlikely to be necessary. The exception is food waste segregation, where people who do not currently have a separate food waste bin perceive such bins to be more unhygienic than general waste bins than do people who have separate food waste bins.

However, there may be a benefit in reducing occasional “behavioural slippage” in individual recycling behaviours, such as separating components of waste and washing containers, since only a minority report that they usually or always do these behaviours. This discrepancy may be related to perceptions

Figure 3.6. Perceptions of household waste management among neighbours.

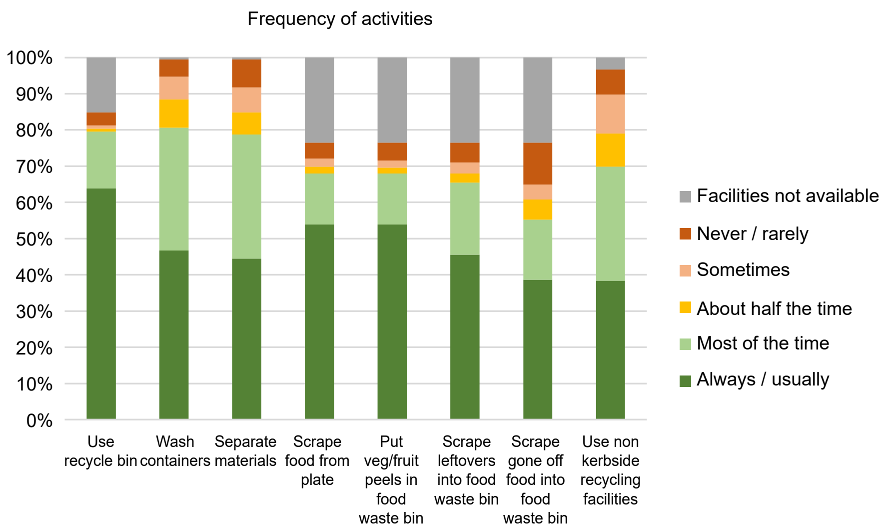

Figure 3.5. Frequency of various household waste management behaviours.

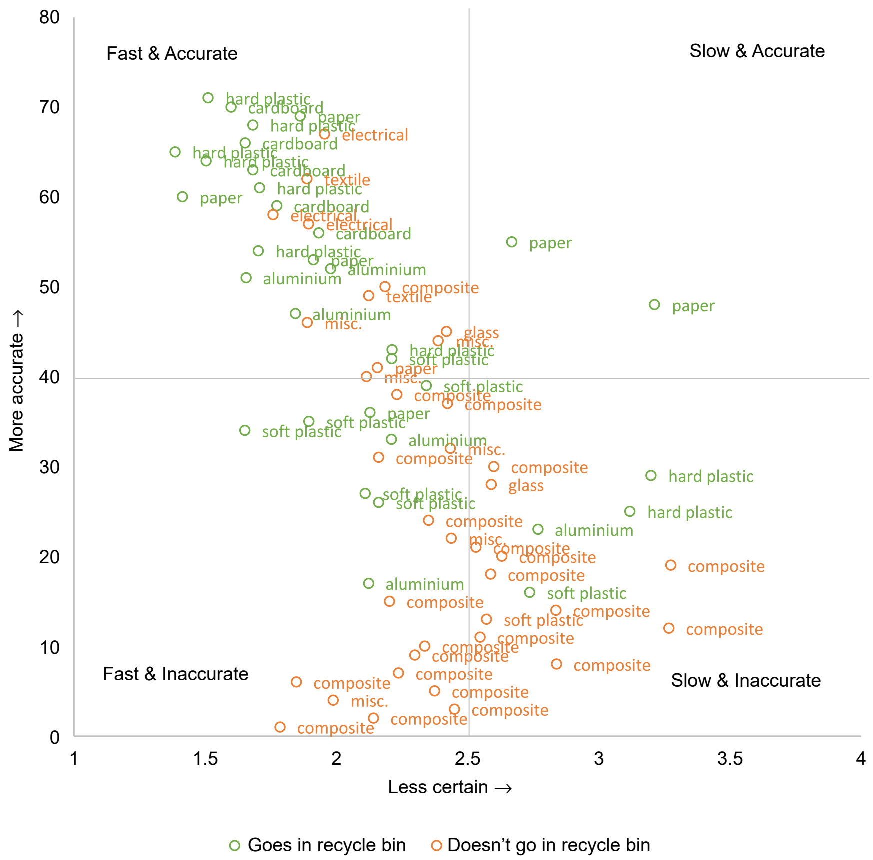

Figure 3.7. Accuracy and response time by disposal method in the recycling choice task.

that others do not recycle properly (see also Ek and Söderberg, 2021). Hence, household recycling may be another environmental domain that suffers "pluralistic ignorance" (Sparkman *et al*., 2022), in which people mistakenly perceive the attitudes or behaviour of a minority to be those of a majority.

The results of the choice task suggest that there is considerable scope for improving the identification of non-recyclable composites. For these items, high-level abstract communication is unlikely to help; item-specific feedback may be more beneficial, as other measures in the study showed that there was little relationship between awareness of material recyclability in standard survey measures and performance in the choice task.

These findings are being used to develop a follow-up RCT with households, to be conducted in late 2022 and 2023 and reported thereafter.

3.4 Diagnostic Experiment on Youth Communications

The research described in this section was carried out by Shane Timmons, Ylva Andersson and Pete Lunn.

3.4.1 Background

Young people are particularly exposed to the consequences of the climate crisis, despite contributing less to it than older generations (Thiery *et al*., 2021). In recent years, social movements such as Fridays for Future have highlighted this generational unfairness to motivate young people to engage with environmental issues. Media coverage implies that young people are more engaged in climate change issues and more strongly support mitigation measures than older generations. However, recent studies, including data from Ireland, show that older people report stronger pro-environmental intentions and are more likely to have engaged in high-impact climate mitigation actions (Spandagos *et al*., 2022; Timmons and Lunn, 2022). Our aim was to provide a detailed understanding of climate change perceptions among young people (aged 16–24 years) in Ireland. To do so, we assessed multiple factors relevant to climate change mitigation: current behaviour; knowledge of mitigation actions; perceptions of self-efficacy and responsibility; future intentions; and support for policy. As part of the assessment of knowledge of mitigation actions, we tested whether receiving accurate information on the mitigative impacts of environmental actions affect pro-environmental motivation.

We also sought to test experimentally whether framing climate change communications along generational lines affects young people's motivations. The general aim of climate change communications to date has been to engender worry as a motivator for action (Goldberg *et al.,* 2021). Generational framing may induce worry and motivate young people to act by highlighting the effects of climate change on their future. However, alternative outcomes are possible. Highlighting generational differences in contributions to climate change could lead young people to believe that older people are less worried than they are and hence less likely to support mitigation. This misperception could in turn lead to intergenerational conflict. This kind of intergroup conflict risks undermining the sort of collective action needed to tackle climate change and demotivating young people from taking action (Masson and Fritsche, 2021). Hence, we tested not only whether generational framing increases self-reported worry about climate change among young people but also whether it alters how worried they perceive older people to be and whether it affects their belief in collective action. Multiple sources now show that concern about climate change in Ireland is high across all age groups (Leiserowitz *et al*., 2021). We further tested whether confronting young people with accurate statistics on the level of worry reported by older people in Ireland alters their belief in collective action.

3.4.2 Methods

The sample consisted of 500 young people, aged 16–24 years, who were recruited by two market research and polling agencies to be broadly nationally representative. Unlike most research on youth perceptions of environmental issues, there was no reliance on participant (or their school's) engagement in climate-related activities to provide a convenience sample, meaning that this study is unlikely to be biased towards "highly engaged" young people.

The study proceeded over multiple stages and took 10 minutes to complete. Participants were asked about their own environment-related behaviour (e.g. diet, use of transport) before being informed that the focus of the study was climate change. All participants read the same definition of climate change, but half the sample ($n = 250$) were randomly assigned to the "generational frame condition" and read information that had been framed in a way to highlight generational differences, inspired by recent media activity. All participants were then asked how worried they are about climate change and how worried they think older generations and other young people are.

After responding, approximately half of the participants ($n = 257$) were randomly assigned to receive feedback on the actual level of worry among older generations, as recorded in previous research (Timmons and Lunn, 2022). They were then asked three questions about their belief in collective action to mitigate climate change.

Next, we asked participants to estimate the mitigative impact of 12 different pro-environmental behaviours on a person's carbon footprint (as done in Timmons and Lunn, 2022). They were asked about their own self-efficacy and responsibility with respect to climate mitigation, as well as that of older people and the government. Approximately half of participants ($n = 247$) were randomised to see accurate information about the mitigative potential of different actions. All participants were then asked how likely they would be to adopt a series of environmental behaviours in the future and about their support for multiple pro-climate policies. Lastly, participants responded to questions on their engagement with and perceptions of their local outdoor amenities. Responses were given on seven-point rating scales.

3.4.3 Results

Participants reported that they themselves were very worried about climate change, with responses showing a strongly negative skew (M = 5.6, SD = 1.33; Figure 3.8). An ordinal logistic regression model showed that participants in the generational frame condition reported being more worried about climate change than those in the control condition (M = 5.8, SD = 1.18 vs M = 5.4, SD = 1.45, respectively; $\beta = 0.036$, $p = 0.017$, $d = 0.25$). Estimates of how worried older people are showed a slightly positive skew and were much lower than self-reported worry (M = 3.9, SD = 1.50). A majority of participants (74%) gave a response below the "correct" estimate of 5.01 and hence could be considered "underestimators".

Belief in collective action was concentrated slightly above the midpoint of the scale (M = 4.6, SD = 1.23).

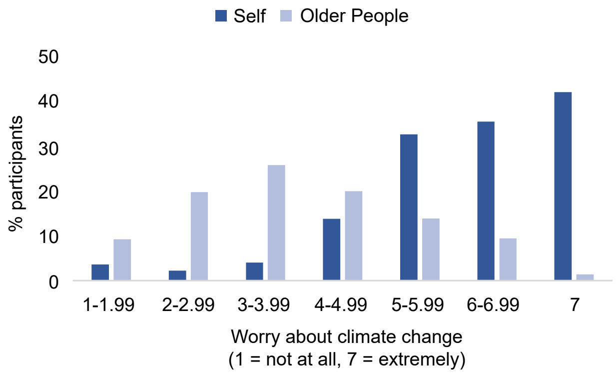

Figure 3.8. Distribution of responses to questions about how worried young people are about climate change and how worried they think older people are, on the same scale.

An ordinal logistic regression model showed that there was no overall effect of frame or seeing how worried older people are on belief in collective action (Table 3.4). However, including an interaction term between whether the participant saw the older people's worry information, and whether they had underestimated older people's worry when asked (model 2), showed that seeing the worry information amplified beliefs in collective action among those who underestimated how worried older generations are, and weakened beliefs in collective action among the minority who had overestimated how worried older generations are (i.e. "overestimators").

Turning to the other survey measures recorded, young people reported feeling highly capable of helping to mitigate the effects of climate change (M = 5.6, SD = 1.41) and viewed themselves as having high-enough responsibility (M = 5.5, SD = 1.43) to do so. The majority reported strong intentions to engage in most pro-environmental behaviours in the future, with half stating that they are likely to engage in high-effort, high-impact behaviours, such as reducing their meat consumption and the number of flights they take. In the long term, about one in three indicated a high likelihood of eating a fully plant-based diet, avoiding flying and living car-free. In general, this is much higher than the proportion of older people that currently engage in these behaviours. The youth sample also reported high levels of support for potential future climate policies, particularly for those that target businesses and industry (Table 3.5).

Despite high levels of climate concern, intentions and support for policy, a minority of young people reported currently engaging in most of the pro-environmental behaviours we recorded. This gap between intention and current action is especially salient when considering the low proportion (6%) who report not eating meat or other animal products, despite eating a plant-based diet being one of the most impactful actions a person can take to reduce their own carbon footprint (as estimated by Wynes and Nicholas, 2017; Wynes *et al.*, 2020).

One potential explanation for the disconnect between attitudes and behaviour is a lack of knowledge about which individual actions are most effective. Knowledge of how different pro-environmental behaviours affect emissions, as evidenced by our multiple choice questions, is poor (Figure 3.9). The average percentage of correct estimates was marginally lower than what would be expected by chance. The source of the error primarily comes from a bias towards overestimating the impact of low-impact behaviours, such as recycling and not littering. Seeing the correct estimates in a brief infographic had no effect on subsequent estimates.

Table 3.4. Ordinal logistic regression models predicting belief in collective action

	Model 1		Model 2	
Variable	Coefficient (95% CI)	*p*-value	Coefficient (95% CI)	*p*-value
Generational frame (Ref: no frame)	0.19 (–0.14 to 0.52)	0.867[a]	0.19 (–0.15 to 0.53)	0.860[a]
Shown OG worry (Ref: not shown)	0.15 (–0.18 to 0.49)	0.181[a]	–0.78 (–1.47 to –0.10)	0.024
Underestimated OG worry (Ref: not underestimated)			–1.63 (–2.19 to –1.08)	< 0.001
Underestimated + shown OG worry			1.34 (0.55 to 2.13)	0.001

The data presented are based on responses from 499 participants. Socio-demographic factors were controlled for in all models.

[a]One-tailed, given pre-registered directional hypothesis.

OG, older generation; Ref., reference category.

Table 3.5. Percentage of young people in favour of various pro-climate policies

Policy	In favour (%)
Fines for businesses that have emissions above a certain level	78
Lower taxes for imported goods that are carbon neutral (with higher taxes for those that are not)	71
Making renewable energy sources, such as wind or solar power, mandatory even if they cost more	65
Ban use of environmentally harmful subsidies in production and import of goods even if it leads to everyday products becoming more expensive	60
Ban on domestic flights (e.g. Dublin to Shannon) unless they provide an essential service	57
Ban on cars in certain parts of towns and city centres (e.g. implement car-free zones)	57
Higher taxes on homes that are not energy efficient, with money collected going towards grants for retrofitting homes (i.e. to pay some of the cost of making homes more energy efficient)	47
Higher taxes on meat, with money collected going to invest in ways to make farming more environmentally friendly	43
Higher taxes on petrol and diesel to fund more public transport	33
A limit on the number of flights any person can take in a year	29

Responses are classified as "in favour" of a policy if scored as 5 or above on the seven-point scale. Percentages are weighted to be nationally representative.

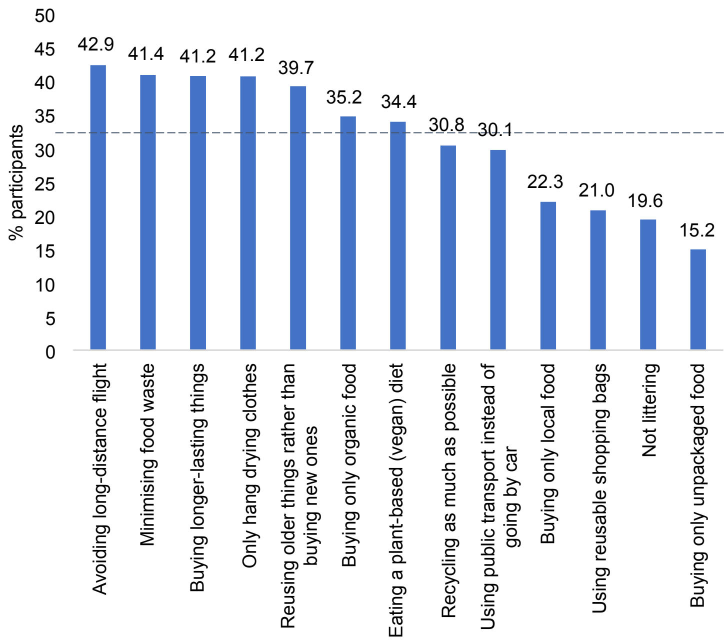

Figure 3.9. Percentages of participants who correctly estimated the impact of each of the pro-environmental behaviours. The dashed line shows the level expected by chance.

Lastly, young people reported that their local outdoor amenities were very important to them and that they enjoyed spending time in them (Figure 3.10). The frequency of visits to local outdoor amenities was one of the most consistent predictors of pro-climate intentions we observed. The association could simply indicate that those who spend time in outdoor areas do so because of their pro-environmental attitudes. However, the relationship between time spent in local amenities and future intentions remained even when we controlled for other pro-environmental behaviours young people currently engage in.

3.4.4 Conclusions and policy implications

The results show that highlighting generational differences in the causes and effects of climate change leads to higher levels of worry among young people than providing standard information on climate change. A large majority (three in four) of young

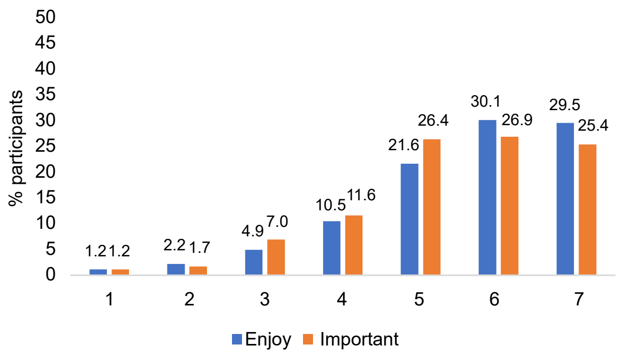

Figure 3.10. Distribution of responses to rating scale question about how important and enjoyable the local environment is for young people.

people underestimate the level of worry that older people report. Confronting young people with this misperception boosts belief in collective climate action. These findings imply that framing climate change communications in generational terms is likely to increase worry among young people but is unlikely to motivate behaviour change. Hence, if communicators wish to reduce worry among young people, for example to attempt to address eco-anxiety (Wu *et al.*, 2020), speaking about climate change in neutral, non-generational terms is likely to help, without undermining young people's belief in collective action or existing intentions to act pro-environmentally.

In countries such as Ireland, where concern for the climate is high, many young people are likely to underestimate the concern of older people. Doing so is associated with lower belief in collective action, but providing accurate information can help promote higher levels of belief. However, if statistical information is shared – as in our experiment – overestimators who are confronted with it are likely to reduce their intentions to act in pro-environmental ways. Hence, a sensible approach for policy may be to communicate the level of concern in general terms, as is done in reports such as Climate Change in the Irish Mind (Leiserowitz *et al.*, 2021).

The survey measures also show that young people in Ireland are highly concerned about the environment. They report strong intentions to engage in most pro-environmental behaviours in the future and high levels of support for future climate policies (even those that are sometimes controversial, such as implementing car-free zones in towns and cities). Exploratory analyses suggest that there are few differences between socio-demographic groups. However, there is considerable scope for informing young people about the relative mitigative potential of different pro-environmental behaviours. Interventions may need to employ engaging communication modes rather than passive modes, such as interactive quizzes rather than infographics (see Timmons and Lunn, 2022). Interventions can be behaviourally informed and experimentally tested.

Lastly, the association between spending time in local outdoor amenities and the strength of pro-climate intentions suggests that targeted interventions that expose young people to nature and increase their connection to it could help them move beyond intentions to change their behaviour. These interventions could also incorporate educational elements as a way to increase climate knowledge about effective actions they can take (Boyd and Scott, 2022; Dabaja, 2022). Considering the multiple benefits of spending time in nature (e.g. Alcock *et al.*, 2014), identifying ways to promote engagement among the minority who rarely visit local amenities is reasonable. Of course, any such interventions would benefit from controlled experimental testing to establish causal relationships.

The findings from the experimental test of generational framing are published in an ESRI working paper (Timmons *et al.*, 2022). The remaining survey results have also been published in an ESRI Survey and Statistical Series report (Andersson *et al.*, 2022).

4 Biodiversity and Agriculture

The research described in this chapter was carried out by Maria Martinez Cillero and Miguel Tovar Reaños.

4.1 Introduction

In this chapter, we summarise the results of two studies that were undertaken in the broad area of biodiversity and agriculture, focusing on alternative designs of agricultural subsidies (section 4.2) and the effects of agricultural subsidy design features on farm labour supply (section 4.3).

4.2 Designing a Green, Equitable and Socially Acceptable Subsidy Scheme

4.2.1 Background

The EU recently announced that, starting in 2023, several environmental provisions will be added to both pillars of the Common Agricultural Policy (CAP): 35% of funds for rural development (which is the main focus of pillar II) will be devoted to agri-environmental commitments.[5] In pillar I, which is focused on direct income support for farmers, "eco-schemes" will be added. These schemes are payments to farmers that are conditional on certain environmental requirements (European Commission, 2019). In the analysis carried out in this study, the resulting rebalancing of the roles of pillars I and II as eco-schemes will be financed by reductions in payments from pillar I.

Historically, there have been three voluntary schemes that gave out agri-environmental payments for a duration of 5 years each: the Rural Environment Protection Scheme (REPS, 1994–2009), the Agri-Environment Options Scheme (AEOS, 2010–2012) and the Green, Low-Carbon, Agri-Environment Scheme (GLAS, 2015–16). Agri-environmental payments are designed to compensate farmers for the adoption of practices that mitigate the negative impacts of farming activities on the environment and enhance rural landscapes (Department of Agriculture, Food and the Marine, 2007). In this study, we quantify the impacts of environmental payment schemes on the economic and environmental performance of farms and simulate the effects of reallocating funds towards environmental payments.

4.2.2 Data and methods

We used data from the representative National Farm Survey (NFS) between 2000 and 2017, obtained from the Irish Social Science Data Archive.[6] We focused on specialist dairy and beef farms for our analysis because dairy production is the largest farming system in Ireland in terms of economic output, while beef is the largest in terms of the number of farms. Dairy farms generate a much higher income per hectare, while beef farms are the most reliant on subsidies to survive economically. Lastly, it is likely that these two sectors will be the target of policy measures aimed at reducing emissions from the agricultural sector in Ireland (Lanigan *et al*., 2019).

We applied stochastic frontier analysis (SFA) to obtain estimates of farm-level technical efficiency and emissions efficiency and to assess the effect of several farm-specific characteristics on this estimate. Farm production technology is analysed by estimating the relationship between inputs and outputs. In this application, SFA measures the distance between a theoretical production frontier and the observed production levels (i.e. technical efficiency) of desirable and undesirable outcomes for dairy and beef farms.

The production frontier is the maximum theoretical output for a given level of inputs. If the output is methane emissions, being further from the frontier (i.e. having a lower methane efficiency) indicates a better environmental performance. In contrast, if the output is economic output, being closer to the frontier is the desired outcome (see Cillero and Reaños, 2022).

5 https://ec.europa.eu/commission/presscorner/detail/en/IP_21_2711 (accessed 9 August 2023).

6 https://www.ucd.ie/issda/data/teagascnationalfarmsurvey/ (accessed 9 August 2023).

4.2.3 Results

We found that technical efficiency is negatively and statistically significantly correlated with REPS payments for both farm types and positively and statistically significantly correlated with GLAS payments for dairy farms. In line with previous literature, we found that receiving higher decoupled support is negatively associated with technical efficiency (Minviel and Latruffe, 2017).

We also simulated three scenarios in which funds were reallocated between decoupled payments and GLAS subsidies: (1) a "flat" allocation where each recipient of the GLAS payment receives the same amount from the additional funds; (2) allocation of additional funds to those farmers with stocking rates below the sample median; 3) allocation of additional funds in direct proportion to current GLAS subsidy receipts. We calculated changes in technical efficiency, methane emission efficiency and income inequality associated with each scenario. Our simulation suggests that increases in GLAS payments financed by decoupled payments can potentially improve environmental gains. As for improvements in technical efficiency, the flat allocation of additional GLAS payments performs slightly better for both types of farms. However, regarding environmental gains, the stocking rate allocation performs best for dairy farms, and the proportional allocation performs better for beef farms. Referring to the distributional impacts, increasing GLAS payments can potentially decrease income inequality under the scenarios analysed for beef farms.

4.2.4 Conclusions and policy implications

Our findings highlight the importance of considering the heterogeneous effects of changes in environmental payment schemes across different farm types. Our simulation results also suggest that there is a trade-off between improving competitiveness and environmental gains. When designing environmental payment schemes, policymakers need to consider that effects differ across farm types and income levels. Because of data limitations, we can consider only emissions directly generated by animal production and have to ignore other sources such as energy or nitrate fertiliser use. Therefore, our measure is likely to under-represent total farm emissions. Should more detailed environmental externality data become available as part of the NFS in the future, more sophisticated methodologies to model total farm GHG emissions could yield fruitful results.

This research has been published in a peer-reviewed journal article (Cillero and Reaños, 2022).

4.3 Farm Labour Supply and Farm Technical and Environmental Efficiency

4.3.1 Background

Changes in agricultural subsidies can affect work time allocation within a farm because they affect the farm's income through two channels. First, they can change the number of hours the farm staff are willing to provide, affecting their income levels. Second, they can directly affect the income of the farm by reducing the level of subsidies received. The higher fixed income could either make off-farm work more attractive, relative to on-farm work, or enable farming families to substitute work for leisure more easily. Policymakers should be interested in these effects because the design of environmental subsidies will bring changes in working time allocation which, at the same time, can have distributional, efficiency and environmental impacts. We investigated these relationships between environmental subsidies, working time allocation and the environmental impact of farming.

4.3.2 Data and methods

The NFS also includes information on whether a farmer has an off-farm job and paid and unpaid hours of on-farm labour supply by the farming family. We modelled working hours, controlling for the farm's profit, the level of environmental subsidies and other socio-economic factors. We also used a logistic model for the probability that the farmer engages in off-farm work. Similar to the first study described above, we used SFA to investigate the impact of labour allocation on production and emissions efficiency.

4.3.3 Results

Our preliminary results show that, for both farm types, on-farm work hours are positively correlated with higher profits but negatively correlated with environmental subsidies. More affluent farms react more strongly to changes in profits and subsidies. Conversely, our estimation of the likelihood of off-farm work shows that higher profits are weakly, but statistically significantly, correlated with a lower probability of off-farm work, while environmental subsidies show a weak positive correlation with off-farm work, but only for dairy farms.

Our SFA shows that off-farm work is associated with reduced technical efficiency, but increased environmental gains, for both farm types. Previous studies have found that off-farm workers are more likely to adopt modern technologies, even though off-farm work can reduce the farm's technical efficiency (Fernandez-Cornejo, 2007). Consequently, off-farm labour could boost technology adoption, reducing the environmental footprint of the farm. Further research is needed to explore this issue further. However, farms with family labour hours that are above the sample mean tend to have higher technical efficiency.

4.3.4 Conclusions and policy implications

Our results indicate that subsidies should be designed with both their direct and indirect impacts in mind. Since environmental subsidies are associated with more off-farm work, which in turn is positively associated with environmental efficiency, their effects could be more significant than initially suspected.

Since higher income farms reduce their on-farm hours more strongly in response to environmental subsidies, these subsidies can also smooth farm income distribution. Policymakers need to be aware of these second-order effects when designing policies.

While the existing literature focuses on the effect on input use and technology adoption, in this study we show that subsidies can also influence time allocation on the farm, which could have implications for the technological options adopted by the farmer and thus the environmental impact of the farm, too.

A draft of this paper has been completed and it is currently being finalised for submission to a peer-reviewed journal.

5 Climate Change

The research described in this section was carried out by Kelly de Bruin, David Meier, Miguel Tovar Reaños and Aykut Mert Yakut.

5.1 Introduction

The level of GHGs we emit is determined by our consumption patterns. Governments introduce taxes and incentives to deter emissions contributing to climate change. However, these policies take a restrictive national approach and focus on reducing national (production) emissions and not global emissions. Given that global and national policies use targets that have been formulated based on GHGs emitted within the borders of a nation, these policies make sense. However, to effectively reduce GHG emissions, we would need to look beyond our borders and consider the emissions that our consumption patterns create in other nations. The two projects described next aim to create a better understanding of the emissions embedded in our consumption and how we may regulate these emissions. The first project uses a national computable general equilibrium (CGE) model (called Ireland Environment, Energy and Economy, I3E) and a global input–output table (EXIOBASE) to estimate the consumption-based emissions of Ireland and the embedded emissions in various consumer goods (section 5.2). The second project examines how we could tax goods based on their carbon content by applying a green VAT. This project applies I3E estimates from the first project and a microsimulation model to examine how a green VAT will impact GHG emissions and the welfare of different households (section 5.3).

5.2 Consumption-based Greenhouse Gas Emissions for Ireland

The research described in this section was carried out by Kelly de Bruin and Aykut Mert Yakut.

5.2.1 Introduction

The purpose of this research is to better understand the GHG emissions associated with consumption within Ireland. GHG emissions are generally estimated and evaluated at the point of production using the so-called production-based accounting method. EU-level and concomitant Irish level emissions targets are set using this approach, and hence policy often focuses on this assessment of emissions. An alternative approach is consumption-based GHG accounting, which focuses on the consumption of goods and services (such as food, clothing, electronic equipment) by residents of a city or country, where GHG emissions are reported by consumption category rather than GHG emission source category. The consumption-based approach has been receiving increasing attention in policymaking, as numerous cities around the world explore their carbon footprint using consumption-based emissions inventories, and countries examine their consumption impact in terms of reaching the Paris Agreement goals.

In essence, the consumption-based emissions methodology corrects for emissions embedded in imports and exports. Consumption-based emissions are, therefore, calculated as:

> Production-based emissions + embedded CO_2 in imported goods − embedded CO_2 in exported goods.

Evaluating emissions on this basis could have important implications for understanding Irish emissions, given the structure of the Irish economy. For example, Ireland exports a large amount of agricultural products containing high levels of embedded emissions, and agricultural production accounts for 30% of Irish GHG emissions.

This work provides an initial assessment of consumption-based emissions, applying an input–output model developed by ESRI, combined with data from EXIOBASE concerning the average emissions per type of imported good. Combining these allows the estimation of consumption-based emissions for Ireland.

5.2.2 Data and methods

The methodology we used combines the I3E model and a global input–output database, EXIOBASE. We will introduce each in turn and then discuss how they are linked and applied.

The I3E model is an intertemporal CGE model that reproduces the structure of the economy in its entirety. It includes productive sectors, households and the government, among others. In the model, the nature of all existing economic transactions among diverse economic agents is quantified. According to micro-economic behaviour, producers/consumers maximise their profits/utility given their budget constraints. In other words, a CGE model examines how inputs and outputs flow between production sectors of the economy and ultimately result in the final goods consumed by households. Note that emissions associated with waste management are also considered here. The waste sector is responsible for 3.3% of global GHG emissions (20% of total global methane emissions).

The production sector comprises 39 representative activities/firms. The main data source used to replicate intersectoral linkages in the Irish economy is the supply and use tables (SUTs) provided by the CSO. The I3E model includes energy flows and emissions in addition to the standard monetary flows. Each production sector produces an economic commodity using labour, capital, material inputs and energy inputs. The I3E model explicitly includes a set of carbon commodities including peat, coal, natural gas, crude oil, fuel oil, liquefied petroleum gas (LPG), petrol, diesel, kerosene and other petroleum products.

EXIOBASE is a global, detailed multi-regional environmentally extended supply–use table (MR-SUT) and input–output table (MR-IOT). It was developed by harmonising and detailing supply–use tables for a large number of countries and estimating emissions and resource extractions by industry. Subsequently, the country supply–use tables were linked via trade, creating an MR-SUT and an MR-IOT from this. The MR-IOT can be used for the analysis of the environmental impacts associated with the final consumption of product groups. EXIOBASE maps imports to each production sector, households and the government in Ireland to an exporting production sector from a specific country. We calculate the emission intensity per production sector for each country and multiply this by the goods imported by Irish production sectors, households and the government. We take into account CO_2, nitrous oxide and methane emissions.

CSO data are used to scale imports up to the current level of each product category. The I3E model is used to determine which agents consume the imported commodity, i.e. production sectors, household types and government. The emissions embedded in the Irish production process are also calculated within I3E, and the proportions of Irish production consumed nationally and exported are determined within I3E. This allows for the calculation of consumption-based emissions. Figure 5.1 represents the methods used in this work.

5.2.3 Results

Applying the methodology described above, we first calculated the emissions associated with activities. The total emissions associated with the production in a specific sector is the sum of the process emissions (as calculated in I3E) and the emissions embedded in the imports used as input for production. We then used this activity-based emissions profile to calculate embedded emissions in commodities (products). Figure 5.2 shows the level of embedded emissions in imports, exports and domestic use. Unsurprisingly, agriculture has a large amount of exported emissions resulting mainly from dairy and beef exports. However, Ireland also imports agricultural emissions through crop imports. The bulk of emissions in mining, petroleum, and public services and goods are imported. The manufacturing and services sectors both import and export emissions, but imports are higher. As would be expected, we find that manufacturing has the largest imported emissions, as

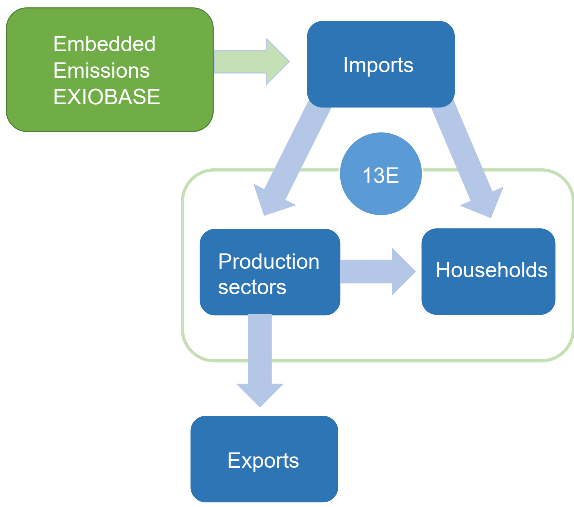

Figure 5.1. Representation of input–output model methodology.

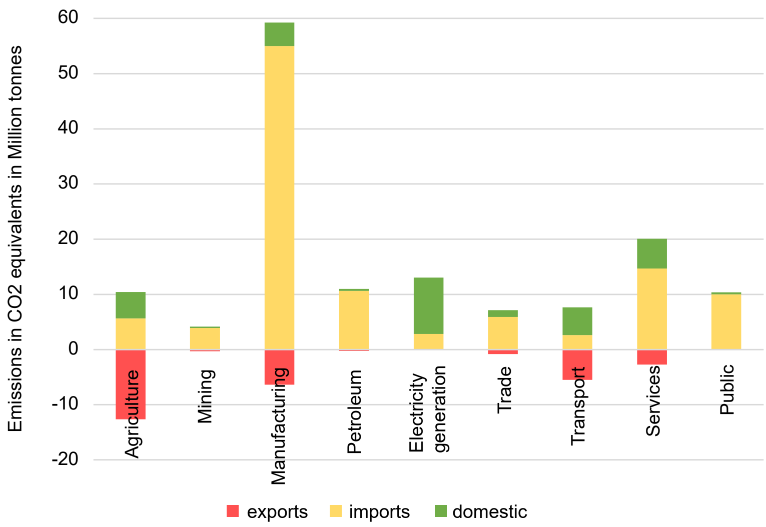

Figure 5.2. Domestic, imported and exported emissions for different goods.

manufacturing imports represent 36% of total imports in monetary terms, and inputs to manufacturing (such as steel) are carbon intensive.

Focusing on the use of imported emissions, Figure 5.3 shows a breakdown of their use. As shown, households and the government use the bulk of imported emissions, whereas the proportion used by production (as inputs or investment) is lower. This shows that the emissions we import are mostly from the consumption of final goods that were produced abroad and not used in the Irish production process.

Figure 5.4 shows the geographical regions from which our imported emissions arise. A large proportion of our embedded emissions originate in the EU,[7] the Middle East and the USA, followed by the UK. Given that the EU, UK and USA are our main trading partners, this is not surprising. What is notable is the high level of emissions imported from the Middle East. Further investigation would be needed to supply a reason for this.

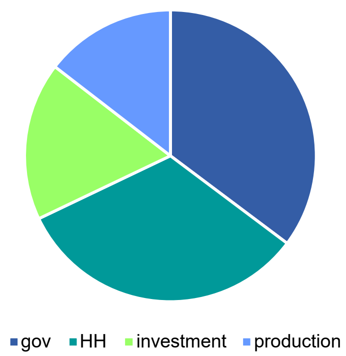

Figure 5.3. The use of imported emissions. gov, government; HH, households.

Lastly, Figure 5.5 plots the total consumption-based emissions compared with production-based emissions for Ireland. The figure is alarming, in that consumption-based emissions are more than double production-based emissions. This shows the importance of considering a consumption-based approach to effectively reduce global emissions.

5.2.4 Conclusions and policy implications

This work represents an initial assessment of consumption-based emissions in Ireland. We applied the I3E model combined with data from the EXIOBASE database for the average emissions per type of imported good to estimate consumption-based emissions for Ireland. The results show that embedded emissions in imports are extremely large, resulting in consumption-based emissions being more than double production-based emissions. Although the bulk of Irish agricultural emissions is exported, imported Irish emissions (for all sectors) far outweigh this. Interestingly, imported emissions originate mainly from the EU, the USA, the Middle East and the UK. Imported emissions are a result of final consumption

7 Note that, on the map (Figure 5.4), the colours indicate the percentage of total imported emissions per country; looking at the EU as a block would result in approximately 20% of emissions originating within the EU.

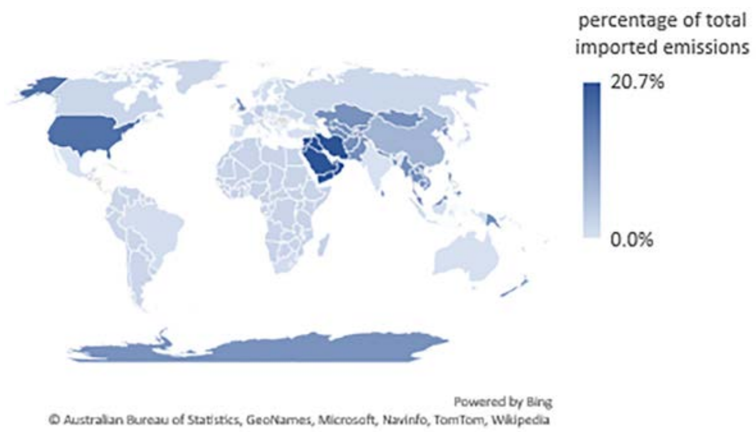

Figure 5.4. The origin of emissions imported to Ireland.

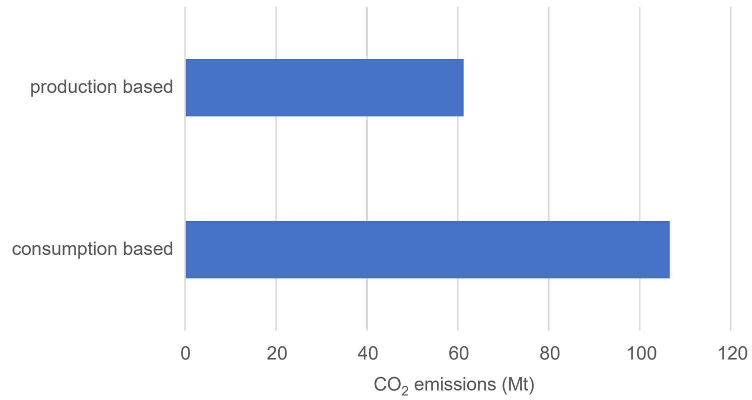

Figure 5.5. Production- versus consumption-based emissions.

by households and the government of goods that are produced abroad and not used in Irish production processes.

This initial project helped in gaining important insights into consumption-based emissions. However, further work would be needed to improve these estimates. Applying other global datasets or making comparisons with other countries applying the same methodology would allow further insights.

This research has been published as an ESRI working paper (De Bruin and Yakut, 2022).

5.3 Green VAT Reform

The research described in this section was carried out by Miguel Tovar Reaños and David Meier.

5.3.1 Introduction

The environmental cost of consuming certain products is not included in their price; thus, Irish consumers cannot factor this cost into their decisions about their level of consumption. This study aimed to simulate the implementation of a new VAT system that attempts to "price in" the environmental distortions associated with different commodities. This therefore discourages consumers' inefficiently high consumption by replacing all existing VAT rates with a uniform base rate of 4% plus a variable carbon tax component that is based on the emissions embedded in each good.

Under the current Irish VAT system, like elsewhere in the EU, rates are assigned independently of environmental considerations. In recent years, using the VAT schedule to steer consumers towards more sustainable consumption patterns has been debated in the EU, but received little attention in the academic literature. Only a few authors (De Camillis and Goralczyk, 2013; Timmermans and Achten, 2018) have outlined a comprehensive environmental reform of VAT. In this project, we simulated the distributional, environmental and economic effects of implementing such a reform in Ireland.

5.3.2 Data and methods

We used the 2015/16 version of the HBS for data on household characteristics, incomes and expenditure patterns. We linked an Irish CGE model, namely I3E, with a global input–output table, EXIOBASE (see section 5.2). EXIOBASE includes emissions estimates and allowed us to estimate the carbon content of different product groups (in tonnes of CO_2-equivalent per euro spent on this group) imported into Ireland. Then, applying the I3E model, we determined the carbon content of each product group by summing the imported embedded emissions in inputs and the emissions associated with the production process (including from the waste management sector, as described in section 5.2). Using this, each household's carbon footprint (in tonnes of CO_2) could be estimated given its expenditure patterns. We multiplied the carbon intensities with our carbon tax to calculate new hypothetical tax rates for each product group. The carbon tax we imposed is €120 per embedded tonne of CO_2-equivalent. We used data from the Revenue Commissioners website to calculate the average existing VAT rates for all eight consumption groups we included in our analysis.[8]

We considered three scenarios: in the first, only the VAT rates are changed; in the second, the VAT rates are changed, and any additional revenue is recycled by increasing social transfers; in the third, revenue is recycled by reducing income tax rates instead. We simulated these scenarios using a behavioural microsimulation model that takes into account demand responses (see van der Ploeg *et al*., 2022). In our simulations, we also explicitly modelled the households' labour supply and estimated the reform's effect on it.

5.3.3 Results

The data show that households with higher overall levels of expenditure have higher footprints for all consumption purposes (Figure 5.6). Most households have an overall annual footprint below the mean of roughly 11.5 footprint tonnes of CO_2-equivalent. Household transport and energy account for by far the highest annual emissions.

Our simulations show that without revenue recycling the green VAT reduces carbon emissions by roughly 6% by reducing consumption, but also reduces labour supply and income tax revenue, as well as overall consumption. It also reduces the welfare of households in the lowest expenditure quartiles more than the welfare of households in the highest quartiles.

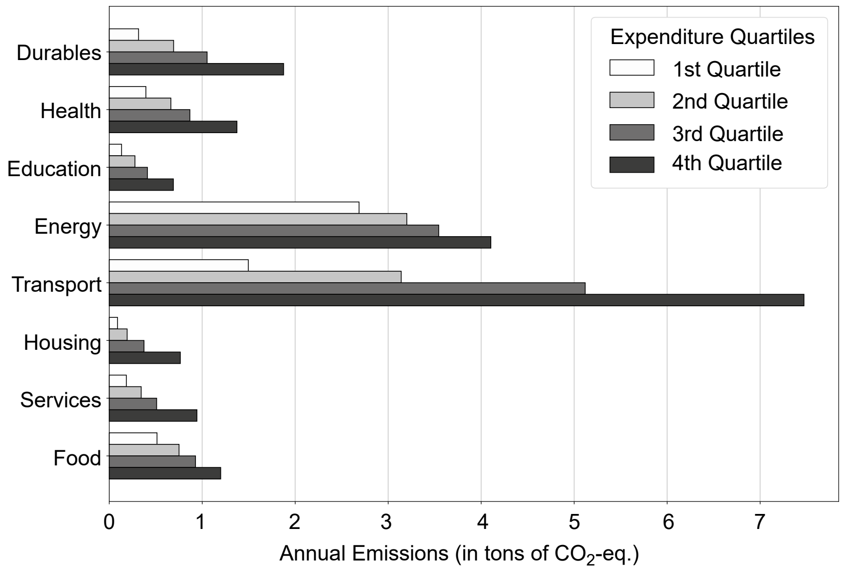

Figure 5.6. Annual carbon footprints by consumption purpose and expenditure quartile. Note that the graph and estimated values mentioned elsewhere in the text are preliminary results.

8 These are food, durables, services, housing, transport, energy, education and health.

Recycling the green VAT revenue by increasing social transfers eliminates the adverse impact of the policy on households in the lowest expenditure quartiles. Reducing income taxes mitigates the adverse impact on welfare, but this effect is most strong for households that are not at the bottom of the expenditure distribution. However, it also mitigates some of the reduction in labour supply. Both revenue recycling mechanisms reduce the simulated drop in emissions by about one percentage point (from 6% to 5%).

5.3.4 Conclusions and policy implications

Our study shows that the carbon footprints of Irish households are strongly driven by expenditure related to energy and transport, and increase with household expenditure. It is therefore consumption of these products and the consumption of high-expenditure households that should be priority targets for policymakers.

Comparing our three scenarios shows that there are trade-offs between the distributional, economic and environmental impacts of the policy package. Our results provide policymakers with a choice about which unwanted side effects of the carbon tax they want to mitigate: the distributional impact or the reduction in working hours. A combination of the two recycling mechanisms simulated here might have the potential to address both simultaneously. Previous studies show that addressing the drawbacks of the tax could increase its popularity (van der Ploeg *et al*., 2022).

The advantage of using VAT as a carbon tax is that as a consumption tax it can influence consumers' decisions directly, which is evidenced by our finding that the new tax schedule is effective in reducing emissions by approximately 6%. The existing literature suggests that it might be more robust against the risk of "carbon leakage", which occurs when measures aimed at reducing emissions are circumvented by moving the pollution elsewhere.

Owing to data limitations, we cannot disaggregate the households' carbon footprints to a level of detail that would allow us to simulate substitution between very similar products with different environmental impacts. Further research is needed to assess the impact of these specific reforms.

This paper has been published as an ESRI working paper (Tovar Reaños *et al*., 2022).

6 Environmental Citizen Science

The research described in this chapter was carried out by Míde Griffin, Seán Lyons and Anne Nolan.

6.1 Introduction

Citizen science is a growing practice that engages the public in scientific research, but gaps remain in our understanding of citizen scientists and the potential benefits that they enjoy from engaging in environmental citizen science. The COVID-19 pandemic has changed the face of citizen science and the lives of citizen scientists, e.g. by increasing awareness of the benefits of citizen science for public health surveillance (Birkin *et al.,* 2021). In the first phase of this project we contributed to the evidence base on who participates in environmental citizen science activities by examining the demographic, socio-economic, attitudinal and health characteristics of a sample of newly recruited biodiversity data recorders in Ireland (Mac Domhnaill *et al*., 2020). The findings suggested that younger people, people who live in urban areas, people who are unemployed and people with lower levels of education were all under-represented in the sample of biodiversity data recorders. Those in the sample were healthier and more physically active than the general population and displayed high levels of concern for the environment.

In this project we used data from a follow-up survey of the same sample of biodiversity data recorders in 2021 to examine changes in the health and wellbeing of this group over the period 2019–2021. As the data collection period for the second survey included the first year of the COVID-19 pandemic, it also contributes to a new and growing literature that considers citizen science in the new era of the COVID-19 pandemic.

6.2 Data and Methods

6.2.1 Biodiversity Recorder Survey

We collaborated with the NBDC in Ireland to conduct a survey of environmental citizen scientists engaged in observation and monitoring activities. The first wave of the Biodiversity Recorder Survey (BRS) was carried out online in early 2019 with a group of individuals who had recently registered as biodiversity data recorders in Ireland (for further details, see Mac Domhnaill *et al*., 2020). The same group was re-surveyed in 2021 (April–June), once again online. The survey uses questions drawn from existing population surveys in Ireland, The Healthy Ireland Survey (adults aged over 15) and TILDA (adults aged over 50). Wave 1 (2019) data from the BRS consisted of 452 respondents and wave 2 (2021) gathered 188 responses; 161 individuals took part in both waves.

6.2.2 Methods

Using descriptive statistics and comparisons of means, we outline the socio-demographic characteristics, health and wellbeing and environmental attitudes of biodiversity data recorders in both waves of the survey. Where possible, data from population surveys such as Healthy Ireland and TILDA, while not collected at the same time as the second wave of the BRS, are presented in order to provide further context.

6.3 Results

Of those who participated in both waves of the BRS, the sample was evenly split between those under 50 years and those over 50 years, and just under half of the respondents were male. Around half of the sample was employed, with less than 20% in retirement. Almost three-quarters of the sample was either married or living with a partner, and the majority had private health insurance, indicating that this was a relatively well-off group.

The general Irish population was seen to be very compliant with COVID-19 public health restrictions (Lunn, 2021), and the data in Figure 6.1 show that this was also true of the sample of BRS respondents: 72% reported leaving the house less often or not at all, while 64% went grocery shopping less often or not at all. Lifestyle changes with regard to interpersonal activities also changed dramatically: 95% travelled to visit family members less often or not at all, and 97% travelled less often to visit friends. Substantial proportions recorded no travel to visit family (47%)

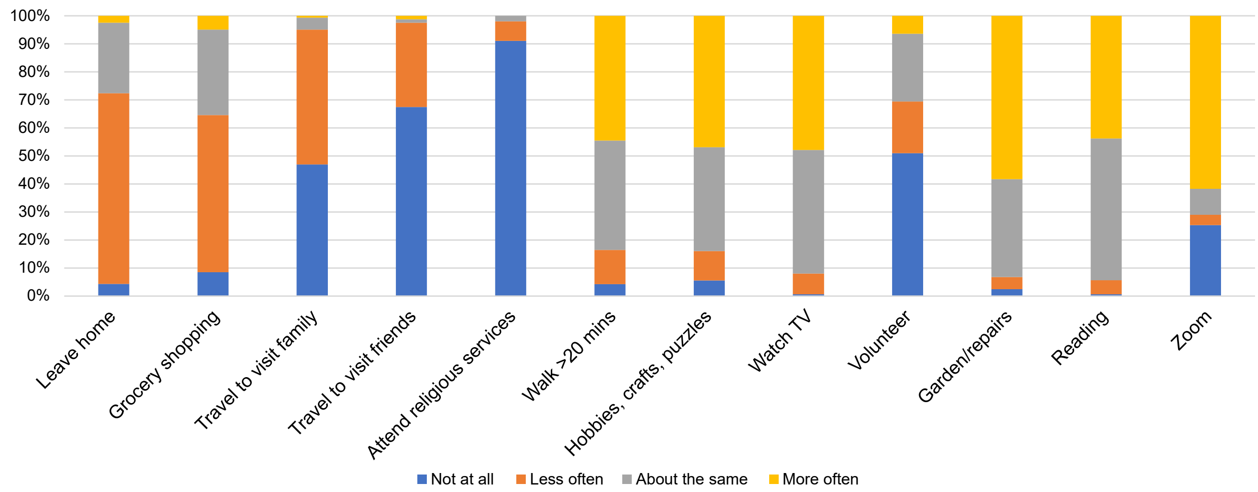

Figure 6.1. Changes in behaviours of BRS respondents since the onset of the COVID-19 pandemic.

or friends (67%) and 91% reported that they were not attending religious services at all during this time. Regarding hobbies and activities, the largest increases were seen in activities that can be done individually or as a household unit: 44% reported that they were walking (more than 20 minutes a day) more often, 46% doing hobbies, crafts or puzzles more often, 48% watching TV and 43% reading more often. Only 6% were doing more volunteering, but nearly 60% were doing garden work or home repairs more frequently. There was also an increase in the use of digital platforms such as Zoom to communicate with groups of friends or family: 61% reported using Zoom (or similar) more often, although 25% reported not using it at all.

The questions on changes in activities in response to the COVID-19 pandemic that are used in the BRS are identical to those used in the 2020 COVID-19 survey of TILDA respondents. While TILDA respondents differ from BRS respondents in their age profile, they too reported substantial changes in their day-to-day activities in response to the pandemic restrictions (Ward *et al*., 2021).

In general, the prevalence of mental ill health and poor wellbeing was low in the BRS sample in both waves. There was little significant change in mental health and wellbeing between 2019 and 2021 for this sample of BRS participants, although, on average, levels of depression, anxiety and loneliness were reported to be higher and quality of life lower in 2021 than in 2019.

Activity levels and most aspects of physical health status did not change significantly between waves.

Respondents were asked to report whether they had walked or done moderate or vigorous exercise during the previous 7 days, and, if so, how much time they spent on each activity on a given day during that period. In wave 2, the sample reported spending 55 minutes walking, 53 minutes doing moderate exercise and around 40 minutes doing vigorous exercise on a given day in the previous week. Using the International Physical Activity Questionnaire (IPAQ) to measure physical activity, we found that 42% of the sample was in the high physical activity category in wave 2, 43% was in the moderate category and 15% was in the low activity category. These patterns were broadly similar in wave 1. It seems that this sample of biodiversity data recorders are relatively active compared with the national average; to put these results in context, only 32% of the population fell into the high physical activity category based on results from the first wave of the Healthy Ireland survey in 2015, and a far higher proportion (31% of the population) fell into the low activity category (Department of Health, 2015).

Lastly, respondents were asked to report on their four main environmental concerns from a given selection (as reported in Table 6.1 for the panel of BRS respondents who took part in both waves). Not surprisingly, given that the sample is a group of biodiversity data recorders, by far the most pressing issue of concern for this group was threats to ecosystems: in wave 1, 92% of respondents cited declining ecosystems in their top four domains of concern. The second most commonly cited issue in wave 1 was river pollution (listed by 57%), followed

Table 6.1. Environmental issues of concern reported by BRS respondents

Environmental issue	Wave 1 (*n*=160)	Wave 2 (*n*=159)	Chi-squared test statistic
Declining ecosystems	92%	88%	1.29
Water shortages	11%	11%	0.00
Floods	6%	8%	0.21
River pollution	57%	65%	2.09
Marine pollution	43%	49%	1.13
Air pollution	14%	11%	0.70
Noise pollution	1%	2%	0.21
Climate change	54%	63%	2.74*
Growing levels of waste	55%	49%	1.13
Agricultural pollution	55%	47%	2.28

*** denotes significant difference between waves at the 90% level.**

by agricultural pollution and waste (both 55%). In wave 2, 88% of respondents listed ecosystems, 65% reported rivers and 63% reported climate in their top four concerns. Statistical testing reveals a statistically significant difference in the proportion of respondents reporting climate change as a top concern.

6.4 Conclusions and Policy Implications

As a growing body of literature shows, citizen scientists can help to contribute to scientific understanding and policy action to tackle phenomena such as biodiversity loss and climate change. This remained true even in the middle of the global public health crisis and severe restrictions to protect public health associated with COVID-19. This research aimed to see how the health and wellbeing of biodiversity recorders in Ireland might have changed over the 2-year study period, in the context of major restrictions on social and economic life at the time of the second wave of the survey. This builds on previous work that characterised the health, wellbeing and physical activity of a group of citizen scientists and how they compared with the general population (Mac Domhnaill *et al.*, 2020). Our research found little evidence of statistically significant changes in the physical health and activity status of this generally healthy and active group. We also found some evidence of changes in the top environmental concerns among this sample of citizen scientists, with an increase in levels of concern about climate change. Understanding the concerns and wellbeing of citizen scientists may help us engage more people in a more meaningful way in this growing practice and achieve local and global objectives, especially in the areas of climate action and environmental protection.

A draft of this paper has been submitted to a peer-reviewed academic journal.

7 Recommendations

7.1 Environment and Health

While the knowledge base on the links between environmental conditions and population health is increasing, gaps remain in our understanding of issues such as the impact of long-term exposure to environmental harms, causal mechanisms and inequalities in exposure. Furthermore, the broader population health effects of exposure to some environmental harms remain relatively under-researched (e.g. poor drinking water quality). A deeper understanding is vital for the design of appropriate policy interventions.

1. Smoky coal bans in Irish towns over the period 2010–2018 resulted in a significant reduction in the prevalence of lung disease among the older population. Nonetheless, in 2021, average levels of $PM_{2.5}$ were above daily and annual WHO AQG limits in many areas of the country. In October 2022, new national standards on the sale and use of solid fuels came into effect, and it will be important to monitor the implementation and effect of the new regulations on population health in the years ahead.
2. The importance of capturing long-term exposure was highlighted by the research that showed that exposure to higher levels of $PM_{2.5}$ pollution over a long period is associated with poorer mental health outcomes. The findings suggest that policymakers should be concerned with the broader health effects of poor air quality, i.e. not only health outcomes related to cardiovascular and respiratory disease.
3. The use of solid fuels for home heating varies substantially across the country, with those in the BMW region significantly more likely to use solid fuels than those resident in other areas of the country, particularly Dublin. Those living in older homes are also much more likely to use solid fuels. Targeted support for transitioning to alternative sources of heating aimed at people living in older dwellings and in certain locations could be effective in reducing the use of solid fuels for domestic heating.
4. The finding that healthcare utilisation in the older population is linked to poor drinking water quality underlines the need to protect the quality of drinking water, thereby improving public health and reducing the burden on healthcare services. This is all the more important in the face of increasing global temperatures, which present greater risks of water contamination, in combination with the ageing of developed societies.
5. While the burden placed by WRDs on the acute hospital system is relatively moderate, WRDs disproportionately affect younger people and a small number of rural or children's hospitals during the spring and summer. This finding in particular will allow limited public health resources to target specific regions at certain times of the year to further reduce morbidity and the costs associated with WRDs.

7.2 Behavioural Science

1. The way information is presented affects the extent to which people attend to that information and also the choices they make. Using insights from behavioural science, the research provided evidence for policymakers and public bodies tasked with communicating with the general public about radon risk (and encouraging testing and remediation) and household waste management, and communicating with young people about climate change.
2. The results imply that understanding of the risk from radon can be improved by a strategy that combines providing households with more information about radon and communicating risk statistics using numerical frequencies. In addition, careful pre-testing of the design features of a radon risk map (including numerical frequencies, e.g. 1 in 5 homes) results in substantially more people being highly willing to test their home for radon.
3. While the public has broadly positive attitudes to proper household waste management, there is

considerable scope for improving the identification of non-recyclable composites (i.e. packaging comprising both cardboard and plastic components). For these items, high-level abstract communication is unlikely to help; item-specific feedback may be more beneficial.

4. Highlighting generational differences in the causes and effects of climate change leads to higher levels of worry among young people than providing standard information on climate change. A large majority (three in four) of young people underestimate the level of worry that older people report. These findings imply that framing climate change communications in generational terms is likely to increase worry among young people but is unlikely to motivate behaviour change. Instead, speaking about climate change in neutral, non-generational terms is preferable, as it will not undermine young people's belief in collective action and existing intentions to act pro-environmentally.

7.3 Biodiversity and Agriculture

Understanding the effects of environmental policy on agricultural performance is important for the design of policy measures aimed at achieving more sustainable and resource-efficient agricultural production. The research used a variety of methods to examine the effect of alternative agricultural subsidy designs on beef and dairy farm performance and on labour supply.

1. The findings highlight the importance of considering the heterogeneous effects of changes in environmental payment schemes across different farm types and income levels. For example, the research identifies a positive relationship between technical efficiency and GLAS payments for dairy farms, in contrast to the negative relationship identified for previous payments of this kind, such as REPS payments for both beef and dairy farms.

2. Furthermore, the results show that agricultural subsidies should be designed with not only their direct impacts but also their indirect effects on farm efficiency and environmental emissions in mind (e.g. farm labour supply). Since environmental subsidies are associated with more off-farm work, which in turn is positively associated with environmental efficiency, their positive environmental effects could be more significant than initially intended.

7.4 Climate Change

The level of GHGs we emit is determined by our consumption patterns. While governments introduce taxes and incentives to deter emissions contributing to climate change, these policies focus on reducing national (production) emissions and not the global level of emissions. The two projects under the climate change theme aimed to create a better understanding of the emissions embedded in our consumption and how we might regulate these emissions.

1. The results show that the emissions embedded in imports are extremely large, resulting in consumption-based emissions being more than double production-based emissions. Although the bulk of Irish agricultural emissions is exported, these are outweighed by emissions embedded in Irish imports (across all sectors). To effectively reduce GHG emissions we need to look beyond our borders and consider the emissions that our consumption patterns create in other nations.

2. An alternative design of the VAT system ("green VAT"), to take into account the environmental costs of consumption, could be an effective mechanism for reducing the emissions embedded in consumption by approximately 6%. However, without revenue recycling, green VAT also reduces labour supply and income tax revenue, as well as overall consumption. It also reduces the welfare of households in the lowest expenditure quartiles more than that of households in the highest quartiles. Policymakers need to consider these trade-offs when designing a potential green VAT schedule.

7.5 Environmental Citizen Science

Lastly, the research provided further evidence for policymakers tasked with engaging the public in environmental citizen science activities. Returning to our cohort of biodiversity data recorders in 2021, the research showed that, while they reduced their social activities during the COVID-19 pandemic substantially, their physical health and activity levels did not change on average.

However, there were changes in the top environmental concerns among this sample of citizen scientists, with an increase in levels of concern about climate change. Understanding the concerns of citizen scientists may help us engage more people in this growing practice and in this way achieve local and global objectives, especially in the areas of climate action and environmental protection.

References

Alcock, I., White, M.P., Wheeler, B.W., Fleming, L.E., Depledge, M.H., 2014. Longitudinal effects on mental health of moving to greener and less green urban areas. *Environmental Science & Technology* 48: 1247–1255. https://doi.org/10.1021/es403688w

Andersson, Y., Timmons, S., Lunn, P., 2022. *Youth Knowledge and Perceptions of Climate Mitigation* (ESRI Survey and Statistical Report Series No. 153). Economic and Social Research Institute, Dublin.

Babaei, A., Alavi, N., Goudarzi, G., Teymouri, P., Ahmadi, K., Rafiee, M., 2015. Household recycling knowledge, attitudes and practices towards solid waste management. *Resources, Conservation and Recycling* 102: 94–100. https://doi.org/10.1016/j.resconrec.2015.06.014

Barlow, P., Lyons, S., Nolan, A., 2021. How perceived adequacy of open public space is related to objective green space and individuals' opinions of area-level quality. *Sustainability* 13. https://doi.org/10.3390/su13158516

Barnes, P., 2016. Sex differences in chronic obstructive pulmonary disease mechanisms. *American Journal of Respiratory and Critical Care Medicine* 193: 813–814. https://doi.org/10.1164/rccm.201512-2379ED

Birkin, L., Vasileiou, E., Stagg, H., 2021. Citizen science in the time of COVID-19. *Thorax* 76: 636–637. https://doi.org/10.1136/thoraxjnl-2020-216673

Boyd, M. and Scott, G.W., 2022. An expert-led outdoor activity can have a lasting impact on the environmental knowledge of participating pupils and adults. *Education 3–13* 50: 696–706. https://doi.org/10.1080/03004279.2021.1899261

Braithwaite, I., Zhang, S., Kirkbride, J., Osborn, D., Hayes, J., 2019. Air pollution (particulate matter) exposure and associations with depression, anxiety, bipolar, psychosis and suicide risk: a systematic review and meta-analysis. *Environmental Health Perspectives* 127: 126002. https://doi.org/10.1289/EHP4595

Carthy, P., Lyons, S., Nolan, A., 2020. Characterising urban green space density and footpath-accessibility in models of BMI. *BMC Public Health* 20: 760. https://doi.org/10.1186/s12889-020-08853-9

Carthy, P., O'Domhnaill, A., O'Mahony, M., Nolan, A., Moriarty, F., Broderick, B., Hennessy, M., Donnelly, A., Naughton, O., Lyons, S., 2021. Local NO2 concentrations and asthma among over-50s in Ireland: a microdata analysis. *International Journal of Epidemiology* 49: 1899–1908.

Chyzheuskaya, A., Cormican, M., Srivinas, R., O'Donovan, D., Prendergast, M., O'Donoghue, C., Morris, D., 2017. Economic assessment of waterborne outbreak of cryptosporidiosis. *Emerging Infectious Disease* 23: 1650. https://doi.org/10.3201/eid2310.152037

Cillero, M. and Reaños, M., 2022. Farm technical and environmental efficiency and subsidy redistribution in Ireland: a simulation approach of possible performance and equity effects. *Journal of Agricultural Economics* 74(2). https://doi.org/10.1111/1477-9552.12509

Clancy, L., Goodman, P., Sinclair, H., Dockery, D., 2002. Effect of air-pollution control on death rates in Dublin, Ireland: an intervention study. *The Lancet* 360: 1210–1214. https://doi.org/10.1016/S0140-6736(02)11281-5

Dabaja, Z.F., 2022. The Forest School impact on children: reviewing two decades of research. *Education 3–13* 50: 640–653. https://doi.org/10.1080/03004279.2021.1889013

De Bruin, K. and Yakut, A., 2022. *The Global Emissions Impact of Irish Consumption*. ESRI Working Paper No. 740. Economic and Social Research Institute, Dublin.

De Camillis, C. and Goralczyk, M., 2013. Towards stronger measures for sustainable consumption and production policies: proposal of a new fiscal framework based on a life cycle approach. *The International Journal of Life Cycle Assessment* 18: 263–272. https://doi.org/10.1007/s11367-012-0460-5

Dempsey, S., Lyons, S., Nolan, A., 2018a. High radon areas and lung cancer prevalence: evidence from Ireland. *Journal of Environmental Radioactivity* 182: 12–19. https://doi.org/10.1016/j.jenvrad.2017.11.014

Dempsey, S., Lyons, S., Nolan, A., 2018b. Urban green space and obesity in older adults: evidence from Ireland. *SSM - Population Health* 4: 206–215. https://doi.org/10.1016/j.ssmph.2018.01.002

Dempsey, S., Devine, M.T., Gillespie, T., Lyons, S., Nolan, A., 2018c. Coastal blue space and depression in older adults. *Health & Place* 54: 110–117. https://doi.org/10.1016/j.healthplace.2018.09.002

Department of Agriculture, Food and the Marine (DAFM), 2007. Terms and conditions of the Rural Environment Protection Scheme (REPS) and Natura 2000 Scheme. DAFM, Dublin.

Department of Health, 2015. *Healthy Ireland Survey 2015*. Department of Health, Dublin.

Eakins, J., Power, B., Dunphy, N., Sirr, G., 2022. *Residential Solid Fuel Use in Ireland and the Transition Away from Solid Fuels*. Environmental Protection Agency, Johnstown Castle, Ireland.

Ek, C. and Söderberg, M., 2021. *Norm-Based Feedback On Household Waste: Large-Scale Field Experiments In Two Swedish Municipalities*. CeCAR Working Paper Series No. 12. University of Gothenburg, Sweden.

EPA (Environmental Protection Agency), 2022. *Air Quality in Ireland 2021*. EPA, Johnstown Castle, Ireland.

European Commission, 2019. *The Post-2020 Common Agricultural Policy: Environmental Benefits and Simplification*. European Commission, Brussels.

Fernandez-Cornejo, J., 2007. *Off-Farm Income, Technology Adoption, and Farm Economic Performance*. United States Department of Agriculture, Washington, DC.

Gładka, A., Blachowski, J., Rymaszewska, J., Zatoński, T., 2021. Investigating relationship between particulate matter air concentrations and suicides using geographic information system. *Psychology, Health & Medicine* 27(10): 2238–2245. https://doi.org/10.1080/13548506.2021.2014059

Goldberg, M., Gustafson, A., Ballew, M., Rosenthal, S., Leiserowitz, A., 2021. Identifying the most important predictors of support for climate policy in the United States. *Behavioural Public Policy* 5: 480–502. https://doi.org/10.1017/bpp.2020.39

Goldenhar, L. and Connell, C., 1991. Effects of educational and feedback interventions on recycling knowledge, attitudes, beliefs, and behaviors. *Journal of Environmental Systems* 21: 321–333.

Hammer, M.S., van Donkelaar, A., Li, C., Lyapustin, A., Sayer, A.M., Hsu, N.C., Levy, R.C., Garay, M.J., Kalashnikova, O.V., Kahn, R.A., Brauer, M., Apte, J.S., Henze, D.K., Zhang, L., Zhang, Q., Ford, B., 2020. Global estimates and long-term trends of fine particulate matter concentrations (1998–2018). *Environmental Science & Technology* 54: 3762.

Hammer, M.S., van Donkelaar, A., Li, C., Lyapustin, A., Sayer, A.M., Hsu, N.C., Levy, R.C., Garay, M.J., Kalashnikova, O.V., Kahn, R.A., Brauer, M., Apte, J.S., Henze, D.K., Zhang, L., Zhang, Q., Ford, B., 2022. *Global Annual PM2.5 Grids from MODIS, MISR and SeaWiFS Aerosol Optical Depth (AOD), 1998–2019, V4.GL.03*. NASA Socioeconomic Data and Applications Center, New York, NY.

Hao, G., Zuo, L., Xiong, P., Chen, L., Liang, X., Jing, C., 2022. Associations of PM2.5 and road traffic noise with mental health: evidence from UK Biobank. *Environmental Research* 207: 112221. https://doi.org/10.1016/j.envres.2021.112221

Huovinen, E., Laine, J., Virtanen, M., Snellman, M., Hujanen, T., Kiiskinen, U., Kujansuu, E., Lumio, J., Ruutu, P., Kuusi, M., 2013. Excess healthcare costs of a large waterborne outbreak in Finland. *Scandinavian Journal of Public Health* 41: 761–766. https://doi.org/10.1177/1403494813490450

Kumbhakar, S., Wang, H., Horncastle, A., 2015. *A Practitioner's Guide to Stochastic Frontier Analysis Using Stata*. Cambridge University Press, Cambridge, UK. https://doi.org/10.1017/CBO9781139342070

Lanigan, G., Donellan, T., Hanrahan, K., Carsten, P., Shalloo, L., Krol, D., Forrestal, P., Farrelly, N., O'Brien, D., Ryan, M., Murphy, P., Caslin, B., Spink, J., Finnan, J., Boland, A., Upton, J., Richards, K., 2019. *An Analysis of Abatement Potential of Greenhouse Gas Emissions in Irish Agriculture 2021–2030*. Teagasc, Oak Park, Carlow, Ireland.

Larsson, C., Andersson, Y., Allestam, G., Lindqvist, A., Nenonen, N., Bergstedt, O., 2014. Epidemiology and estimated costs of a large waterborne outbreak of norovirus infection in Sweden. *Epidemiology and Infection* 142: 592–600. https://doi.org/10.1017/S0950268813001209

Leiserowitz, A., Carman, S., Rosenthal, L., Neyens, J., Desmond, S., Smith, M., Rochford, J., O'Mahony, J., Reaper, L., 2021. *Climate Change in the Irish Mind*. Yale Program on Climate Change Communication, New Haven, CT.

Lunn, P., 2021. Coronavirus in Ireland: one behavioural scientist's view. *Mind & Society* 20: 229–233. https://doi.org/10.1007/s11299-021-00275-3

Lyons, S., 2019. *Research on Aspects of Ireland's Environment, Consumer Behaviour and Health: ESRI Environment Research Programme 2016–2018 (EPA Research Report No. 295)*. Environmental Protection Agency, Johnstown Castle, Ireland.

Lyons, S., Mao, L., Nolan, A., O'Sullivan, V., 2023. The effect of "smoky" coal bans on chronic lung disease among older people in Ireland. *Economics & Human Biology* 50: 101275. https://doi.org/10.1016/j.ehb.2023.101275

Mac Domhnaill, C., Lyons, S., Nolan, A., 2020. The citizens in citizen science: demographic, socioeconomic, and health characteristics of biodiversity recorders in Ireland. *Citizen Science Theory and Practice* 5(1): 16.

Masson, T. and Fritsche, I., 2021. We need climate change mitigation and climate change mitigation needs the 'We': a state-of-the-art review of social identity effects motivating climate change action. *Current Opinion in Behavioral Sciences* 42: 89–96. https://doi.org/10.1016/j.cobeha.2021.04.006

Minviel, J. and Latruffe, L., 2017. Effect of public subsidies on farm technical efficiency: a meta-analysis of empirical results. *Applied Economics* 49: 213–226. https://doi.org/10.1080/00036846.2016.1194963

Mohan, G. and Lyons, S., 2022. The association between *E.coli* exceedances in drinking water supplies and healthcare utilisation of older people. *PLOS ONE* 17(9).

Nolan, A., 2020. *Research on Aspects of Ireland's Environment, Consumer Behaviour and Health: ESRI Environment Research Programme 2018–2020 (EPA Research Report No. 358).* Environmental Protection Agency, Johnstown Castle, Ireland.

Poortinga, W., Bronstering, K., Lannon, S., 2011. Awareness and perceptions of the risks of exposure to indoor radon: a population-based approach to evaluate a radon awareness and testing campaign in England and Wales. *Risk Analysis* 31: 1800–1812. https://doi.org/10.1111/j.1539-6924.2011.01613.x

Ren, T., Yu, X., Yang, W., 2019. Do cognitive and non-cognitive abilities mediate the relationship between air pollution exposure and mental health? *PLOS ONE* 14: e0223353. https://doi.org/10.1371/journal.pone.0223353

Schraufnagel, D., Balmes, J., Cowl, C., De Matteis, S., Jung, S., Mortimer, K., Perez-Padilla, R., Rice, M., Riojas-Rodriguez, H., Sood, A., Thurston, G., To, T., Vanker, A., Wuebbles, D., 2019. Air pollution and noncommunicable diseases: a review by the Forum of International Respiratory Societies' Environmental Committee, part 2: air pollution and organ systems. *Chest* 155: 417–426. https://doi.org/10.1016/j.chest.2018.10.041

Shiels, M., 2003. *The Quiet Revolution*. The O'Brien Press, Dublin.

Spandagos, C., Tovar Reaños, M., Lynch, M., 2022. Public acceptance of sustainable energy innovations in the European Union: a multidimensional comparative framework for national policy. *Journal of Cleaner Production* 340: 130721. https://doi.org/10.1016/j.jclepro.2022.130721

Sparkman, G., Geiger, N., Weber, E., 2022. Americans experience a false social reality by underestimating popular climate policy support by nearly half. *Nature Communications* 13: 4779. https://doi.org/10.1038/s41467-022-32412-y

Thiery, W., Lange, S., Rogelj, J., Schleussner, C.-F., Gudmundsson, L., Seneviratne, S.I., Andrijevic, M., Frieler, K., Emanuel, K., Geiger, T., Bresch, D.N., Zhao, F., Willner, S.N., Büchner, M., Volkholz, J., Bauer, N., Chang, J., Ciais, P., Dury, M., François, L., Grillakis, M., Gosling, S.N., Hanasaki, N., Hickler, T., Huber, V., Ito, A., Jägermeyr, J., Khabarov, N., Koutroulis, A., Liu, W., Lutz, W., Mengel, M., Müller, C., Ostberg, S., Reyer, C.P.O., Stacke, T., Wada, Y., 2021. Intergenerational inequities in exposure to climate extremes. *Science* 374: 158–160. https://doi.org/10.1126/science.abi7339

Timmermans, B. and Achten, W., 2018. From value-added tax to a damage and value-added tax partially based on life cycle assessment: principles and feasibility. *The International Journal of Life Cycle Assessment* 23: 2217–2247. https://doi.org/10.1007/s11367-018-1439-7

Timmons, S. and Lunn, P., 2022. *Public Understanding of Climate Change and Support for Mitigation.* ESRI Research Series No. 135. Economic and Social Research Institute, Dublin.

Timmons, S. and Lunn, P., 2023. Using information provision and interactive risk maps to motivate testing for radon. *Journal of Environmental Psychology* 89: 102057. https://doi.org/10.1016/j.jenvp.2023.102057

Timmons, S., Andersson, Y., Lunn, P., 2022. *Framing Climate Change as a Generational Issue: Experimental Effects on Youth Worry, Motivation and Belief in Collective Action*. ESRI Working Paper No. 731. Economic and Social Research Institute, Dublin.

Tovar Reaños, M., De Bruin, K., Meier, D., Yakut, A., 2022. *Economic and Distributional Impacts of Turning the Value-Added Tax into a Carbon Tax*. ESRI Working Paper No. 739. Economic and Social Research Institute, Dublin.

van der Ploeg, F., Rezai, A., Tovar Reaños, M., 2022. Gathering support for green tax reform: evidence from German household surveys. *European Economic Review* 141: 103966. https://doi.org/10.1016/j.euroecorev.2021.103966

Ward, M., O'Mahoney, P., Kenny, R., 2021. *Altered Lives in a Time of Crisis: The Impact of the COVID-19 Pandemic on the Lives of Older Adults in Ireland. Findings from The Irish Longitudinal Study on Ageing.* The Irish Longitudinal Study on Ageing, Dublin.

Wenger, J., Arndt, J., Buckley, P., Hellebust, S., McGillicuddy, E., O'Connor, I., Sodeau, J., Wilson, E., 2020. *Source Apportionment of Particulate Matter in Urban and Rural Residential Areas of Ireland (SAPPHIRE) (EPA Research Report No. 318).* Environmental Protection Agency, Johnstown Castle, Ireland.

WHO (World Health Organization), 2016. *Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease*. WHO, Geneva.

WHO (World Health Organization), 2021. *WHO Global Air Quality Guidelines: Particulate Matter (PM2.5 and PM10), Ozone, Nitrogen Dioxide, Sulphur Dioxide and Carbon Monoxide*. WHO, Geneva.

Wu, J., Snell, G., Samji, H., 2020. Climate anxiety in young people: a call to action. *The Lancet Planetary Health* 4: e435–e436. https://doi.org/10.1016/S2542-5196(20)30223-0

Wynes, S. and Nicholas, K., 2017. The climate mitigation gap: education and government recommendations miss the most effective individual actions. *Environmental Research Letters* 12: 074024. https://doi.org/10.1088/1748-9326/aa7541

Wynes, S., Zhao, J., Donner, S., 2020. How well do people understand the climate impact of individual actions? *Climatic Change* 162: 1521–1534. https://doi.org/10.1007/s10584-020-02811-5

Abbreviations

BMW	Border, Midland and Western
CGE	Computable general equilibrium
CI	Confidence interval
CSO	Central Statistics Office
ED	Emergency department
ESRI	Economic and Social Research Institute
GHG	Greenhouse gas
GLAS	Green, Low-Carbon, Agri-Environment Scheme
GP	General practitioner
HIPE	Hospital In-Patient Enquiry
HRP	Household reference person
I3E	Ireland Environment, Energy and Economy
ICD-10-AM	International Statistical Classification of Diseases and Related Health Problems
M	Mean
NBDC	National Biodiversity Data Centre
NFS	National Farm Survey
$PM_{2.5}$	Particulate matter consisting of particles with a diameter of 2.5 μm or less
REPS	Rural Environment Protection Scheme
SD	Standard deviation
SFA	Stochastic frontier analysis
TILDA	The Irish Longitudinal Study on Ageing
VAT	Value added tax
WHO	World Health Organization
WRD	Water-related disease

An Ghníomhaireacht Um Chaomhnú Comhshaoil

Tá an GCC freagrach as an gcomhshaol a chosaint agus a fheabhsú, mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ar thionchar díobhálach na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialáil: Rialáil agus córais chomhlíonta comhshaoil éifeachtacha a chur i bhfeidhm, chun dea-thorthaí comhshaoil a bhaint amach agus díriú orthu siúd nach mbíonn ag cloí leo.

Eolas: Sonraí, eolas agus measúnú ardchaighdeáin, spriocdhírithe agus tráthúil a chur ar fáil i leith an chomhshaoil chun bonn eolais a chur faoin gcinnteoireacht.

Abhcóideacht: Ag obair le daoine eile ar son timpeallachta glaine, táirgiúla agus dea-chosanta agus ar son cleachtas inbhuanaithe i dtaobh an chomhshaoil.

I measc ár gcuid freagrachtaí tá:

Ceadúnú

- Gníomhaíochtaí tionscail, dramhaíola agus stórála peitril ar scála mór;
- Sceitheadh fuíolluisce uirbigh;
- Úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe;
- Foinsí radaíochta ianúcháin;
- Astaíochtaí gás ceaptha teasa ó thionscal agus ón eitlíocht trí Scéim an AE um Thrádáil Astaíochtaí.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil

- Iniúchadh agus cigireacht ar shaoráidí a bhfuil ceadúnas acu ón GCC;
- Cur i bhfeidhm an dea-chleachtais a stiúradh i ngníomhaíochtaí agus i saoráidí rialáilte;
- Maoirseacht a dhéanamh ar fhreagrachtaí an údaráis áitiúil as cosaint an chomhshaoil;
- Caighdeán an uisce óil phoiblí a rialáil agus údaruithe um sceitheadh fuíolluisce uirbigh a fhorfheidhmiú
- Caighdeán an uisce óil phoiblí agus phríobháidigh a mheasúnú agus tuairisciú air;
- Comhordú a dhéanamh ar líonra d'eagraíochtaí seirbhíse poiblí chun tacú le gníomhú i gcoinne coireachta comhshaoil;
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Dramhaíola agus Ceimiceáin sa Chomhshaol

- Rialacháin dramhaíola a chur i bhfeidhm agus a fhorfheidhmiú lena n-áirítear saincheisteanna forfheidhmithe náisiúnta;
- Staitisticí dramhaíola náisiúnta a ullmhú agus a fhoilsiú chomh maith leis an bPlean Náisiúnta um Bainistíocht Dramhaíola Guaisí;
- An Clár Náisiúnta um Chosc Dramhaíola a fhorbairt agus a chur i bhfeidhm;
- Reachtaíocht ar rialú ceimiceán sa timpeallacht a chur i bhfeidhm agus tuairisciú ar an reachtaíocht sin.

Bainistíocht Uisce

- Plé le struchtúir náisiúnta agus réigiúnacha rialachais agus oibriúcháin chun an Chreat-treoir Uisce a chur i bhfeidhm;
- Monatóireacht, measúnú agus tuairisciú a dhéanamh ar chaighdeán aibhneacha, lochanna, uiscí idirchreasa agus cósta, uiscí snámha agus screamhuisce chomh maith le tomhas ar leibhéil uisce agus sreabhadh abhann.

Eolaíocht Aeráide & Athrú Aeráide

- Fardail agus réamh-mheastacháin a fhoilsiú um astaíochtaí gás ceaptha teasa na hÉireann;
- Rúnaíocht a chur ar fáil don Chomhairle Chomhairleach ar Athrú Aeráide agus tacaíocht a thabhairt don Idirphlé Náisiúnta ar Ghníomhú ar son na hAeráide;
- Tacú le gníomhaíochtaí forbartha Náisiúnta, AE agus NA um Eolaíocht agus Beartas Aeráide.

Monatóireacht & Measúnú ar an gComhshaol

- Córais náisiúnta um monatóireacht an chomhshaoil a cheapadh agus a chur i bhfeidhm: teicneolaíocht, bainistíocht sonraí, anailís agus réamhaisnéisiú;
- Tuairiscí ar Staid Thimpeallacht na hÉireann agus ar Tháscairí a chur ar fáil;
- Monatóireacht a dhéanamh ar chaighdeán an aeir agus Treoir an AE i leith Aeir Ghlain don Eoraip a chur i bhfeidhm chomh maith leis an gCoinbhinsiún ar Aerthruailliú Fadraoin Trasteorann, agus an Treoir i leith na Teorann Náisiúnta Astaíochtaí;
- Maoirseacht a dhéanamh ar chur i bhfeidhm na Treorach i leith Torainn Timpeallachta;
- Measúnú a dhéanamh ar thionchar pleananna agus clár beartaithe ar chomhshaol na hÉireann.

Taighde agus Forbairt Comhshaoil

- Comhordú a dhéanamh ar ghníomhaíochtaí taighde comhshaoil agus iad a mhaoiniú chun brú a aithint, bonn eolais a chur faoin mbeartas agus réitigh a chur ar fáil;
- Comhoibriú le gníomhaíocht náisiúnta agus AE um thaighde comhshaoil.

Cosaint Raideolaíoch

- Monatóireacht a dhéanamh ar leibhéil radaíochta agus nochtadh an phobail do radaíocht ianúcháin agus do réimsí leictreamaighnéadacha a mheas;
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha;
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta;
- Sainseirbhísí um chosaint ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Ardú Feasachta agus Faisnéis Inrochtana

- Tuairisciú, comhairle agus treoir neamhspleách, fianaise-bhunaithe a chur ar fáil don Rialtas, don tionscal agus don phobal ar ábhair maidir le cosaint comhshaoil agus raideolaíoch;
- An nasc idir sláinte agus folláine, an geilleagar agus timpeallacht ghlan a chur chun cinn;
- Feasacht comhshaoil a chur chun cinn lena n-áirítear tacú le hiompraíocht um éifeachtúlacht acmhainní agus aistriú aeráide;
- Tástáil radóin a chur chun cinn i dtithe agus in ionaid oibre agus feabhsúchán a mholadh áit is gá.

Comhpháirtíocht agus Líonrú

- Oibriú le gníomhaireachtaí idirnáisiúnta agus náisiúnta, údaráis réigiúnacha agus áitiúla, eagraíochtaí neamhrialtais, comhlachtaí ionadaíocha agus ranna rialtais chun cosaint chomhshaoil agus raideolaíoch a chur ar fáil, chomh maith le taighde, comhordú agus cinnteoireacht bunaithe ar an eolaíocht.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil

Tá an GCC á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóir. Déantar an obair ar fud cúig cinn d'Oifigí:

1. An Oifig um Inbhunaitheacht i leith Cúrsaí Comhshaoil
2. An Oifig Forfheidhmithe i leith Cúrsaí Comhshaoil
3. An Oifig um Fhianaise agus Measúnú
4. An Oifig um Chosaint ar Radaíocht agus Monatóireacht Comhshaoil
5. An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tugann coistí comhairleacha cabhair don Ghníomhaireacht agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

epa Research

EPA Research

Webpages: www.epa.ie/our-services/research/
LinkedIn: www.linkedin.com/showcase/eparesearch/
Twitter: @EPAResearchNews
Email: research@epa.ie