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State of Play of Air Science Research in Ireland: Discussion Document

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Roinn Cumarsáide, Gníomhaithe ar son na hAeráide & Comhshaoil
Department of Communications, Climate Action & Environment

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ENVIRONMENTAL PROTECTION AGENCY

The Environmental Protection Agency (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.

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Regulation: *We implement effective regulation and environmental compliance systems to deliver good environmental outcomes and target those who don't comply.*

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- large scale industrial activities *(e.g. pharmaceutical, cement manufacturing, power plants)*;
- intensive agriculture *(e.g. pigs, poultry)*;
- the contained use and controlled release of Genetically Modified Organisms *(GMOs)*;
- sources of ionising radiation *(e.g. x-ray and radiotherapy equipment, industrial sources);*
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- Monitoring and reporting on Bathing Water Quality.

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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:

- Office of Environmental Sustainability
- Office of Environmental Enforcement
- Office of Evidence and Assessment
- Office of Radiological Protection
- Office of Communications and Corporate Services

The EPA is assisted by an Advisory Committee of twelve members who meet regularly to discuss issues of concern and provide advice to the Board.

EPA RESEARCH PROGRAMME 2014–2020

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(2014-CCRP-FS.20)

Prepared for the Environmental Protection Agency

by

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The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

The purpose of this discussion document is to help identify knowledge gaps and priorities for air science research in Ireland. A detailed review of relevant literature at domestic, European and international levels has been carried out with particular focus on nitrogen oxides (NO_x), particulate matter (PM_{10} and $PM_{2.5}$), ozone, sulfur dioxide (SO_2), volatile organic compounds (VOCs), black carbon (BC), ammonia (NH_3) and persistent organic pollutants (POPs). Past and ongoing Environmental Protection Agency (EPA) research activities related to air quality in Ireland have been investigated through a combination of structured interviews, meetings and analysis of review documents.

The air science theme is broad and research has in the past been somewhat dispersed across institutions within Ireland. This can lead to difficulties in identifying emerging research requirements and in some instances to duplication of certain research efforts. This review has concluded that social science and air quality should become more integrated to achieve clean air on a sustainable basis. Future policy interventions will need to consider behavioural change together with technological change, and the research must seek to understand the links between air quality and societal behaviour.

Although a broad theme, there are significant crossovers in much air science research, both domestically and internationally. Facilitating workshops to bring relevant people together would help with research co-ordination. Researchers should also be encouraged to become members of steering committees on other relevant research projects. The establishment of sub-themes within the air science field would help in this regard. Researchers should be encouraged to join any relevant subgroups and to contribute to workshops. Suggested sub-themes are (1) air quality modelling (to include the establishment of a modelling advisory committee); (2) air quality monitoring and emerging techniques, emissions and measurements; (3) health and environmental effects of air pollution and indoor air pollution; and (4) air pollution and climate change. An open research call from the EPA could serve as a means to foster innovation within the research community and encourage novel projects within these pre-identified sub-themes. There is now a clear need for research calls to foster a more interdisciplinary approach, and for large-scale projects that would allow the major research teams in Ireland to work together.

Overall, it is evident from this review that improvements in regular and reliable air quality monitoring are required (including an expansion of the number of aerosol mass spectrometers). Such data are highly relevant and necessary for a range of applications within the air science field, including continued improvements in, and applications of, air quality models. The development of a multipurpose modelling framework should be a next step for Ireland, and success in this regard will likely require the establishment of a modelling advisory committee to ensure that all aspects of development proceed in a co-ordinated manner.

The shift towards $PM_{2.5}$ as the PM fraction of most relevance necessitates improvements in our understanding of the organic aerosol fractions and better quantification of PM modelling frameworks. BC and brown carbon are similarly relevant and research should now point towards the development of a robust inventory for BC. Research gaps regarding bioaerosols and persistent organic pollutants have also been identified. This review document provides details and justification for potential future research directions in each of these fields, and a number of specific research projects within the air science field are also suggested.

Capacity development will be required to achieve maximum benefit from research on national and international levels and, furthermore, to achieve the aims and objectives set out in the EPA's research strategy. Central to this will be the development and maintenance of a knowledge base and the communication of research outputs in a manner that facilitates follow-on work.

1 Introduction

This discussion document aims to assist in the co-ordination of the knowledge and expertise needed to predict and manage Ireland's air quality. This work is highly relevant to the Environmental Protection Agency's (EPA's) 2020 Vision – Protecting and Improving Ireland's Environment, a formal strategy that promotes state-of-the-art research to inform policy-makers and effect change, supporting and publishing environmental research on national and regional air quality (AQ) forecasting, improving emission inventories and reducing uncertainty. The report was prepared as part of the EPA Research Fellowship on Air Science 2014-CCRP-FS.20.

The health impacts from particulate matter (PM) fell by around 20% between 2000 and 2010 (European Commission, 2013a), which can in part be attributed to the stimulation of innovation in pollution abatement resulting from European Union (EU) air policy. The Clean Air for Europe (CAFE) Directive 2008/50/EC came into force on 11 June 2008 and defines short- and long-term limit values for nitrogen oxides (NO_x) and PM_{10}, as well as introducing an annual mean limit value for $PM_{2.5}$, which came into force on 1 January 2015. Other species regulated by this Directive include benzene, ozone, sulfur dioxide (SO_2), carbon monoxide (CO) and lead. These limits are transposed into Irish law by the Air Quality Regulations (DELG, 2002) as amended by the Arsenic, Cadmium, Mercury, Nickel and Polycyclic Aromatic Hydrocarbons in Ambient Air Regulations (DEHLG, 2009) and the Ozone in Ambient Air Regulations 2004 (DEHLG, 2004). The World Health Organization (WHO) has developed guideline standards for AQ which are tighter than current EU AQ standards and which, if adopted by the EU, will pose a challenge for Ireland to meet in the future.

As part of the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC), Ireland has committed to mitigating short-lived climate pollutants. Co-ordinated action is needed across environmental management, industrial, agricultural, public health and climate change communities worldwide to drive climate change mitigation policies.

Economic and technologically feasible solutions are required to combat climate change while simultaneously improving Ireland's AQ by maximising synergies between the standards outlined in the CAFE Directive and those associated with climate change mitigation, and by considering the objectives for reducing health and environmental impacts detailed in the new Clean Air Policy Package for Europe (European Commission, 2013b). The CAFE package describes AQ issues and sets out new interim objectives for reducing health and environmental impacts up to 2030. Necessary emission reduction requirements are defined for the key pollutants, together with the necessary policy agenda to achieve these objectives. The proposals include the transposition into EU law of the EU's new international obligations, agreed under the amended Gothenburg Protocol, and intermediate reduction obligations (by 2025) to maintain the trajectory towards 2030. In this regard two new air pollutants are included in the emission reduction proposal, primary $PM_{2.5}$ (which has serious health impacts and affects climate change) and methane (CH_4) (a key short-lived climate pollutant).

Irish researchers, policymakers and other stakeholders need to participate in and contribute to key European-level research programmes, both to inform policy development and to identify environmental pressures. Ireland, while currently involved in a number of EU initiatives, does not make full use of the available outputs. There is a need for the efficient integration of Ireland into such programmes through direct interaction of, and contributions by, relevant researchers. This will help to ensure that outputs are utilised to their full capacity wherever possible.

In order to progress further in the air science field on an international scale, Ireland needs to link the accountability chain across environmental and social sectors. Synthesising and communicating results of research – in areas such as local AQ modelling, monitoring and management; exposure studies; short-lived climate factors; economic, transport and exposure modelling; impacts of policy and management changes on behaviours; and overall AQ – should be performed on a routine basis at national level. There is a need to identify and foster involvement in relevant programmes/initiatives and synergies with EPA research at an early stage, which will involve relevant researchers and EPA personnel in identified programmes.

This discussion document has arisen from a detailed review of relevant literature at domestic, European and international levels. Past and ongoing EPA research activities related to AQ in Ireland have been investigated. The review has considered local air pollutants outlined in the CAFE Directive, including NO_x, PM_{10}, $PM_{2.5}$, ozone and SO_2, as well as short-lived climate change drivers. The discussion document aims to inform research direction and identify gaps in the field.

This review considered domestically-funded and European-funded AQ research. The current state of national knowledge was ascertained through a review, which included relevant peer-reviewed academic literature, national reports and guidance documents. Past and ongoing research projects offer a potential source of high-resolution information for use in adaptation planning or data streaming between projects to enable knowledge transfer and maximum resource efficiency.

A review of EU initiatives, programmes and large-scale research projects was also carried out. This included assessment of activities, outputs and potential applications in Ireland of programmes such as Copernicus/GMES (MACC II), FAIRMODE, EIONET, large-scale EU-funded research projects (e.g. ESCAPE) and relevant EU COST actions, together with research projects funded under the Seventh Framework Programme for Research and Technological Development (FP7). Structured interviews with researchers in the field of air science in Ireland and online questionnaires were also used to inform this review.

2 Strategy Aims and Objectives

Under the EPA's climate change pillar in the 2014–2020 research strategy, theme 4 aims to inform pathways for the achievement of the highest AQ standards in Ireland and to advance the integrated assessment of air pollution, short-lived climate forcers and other, wider environmental issues. Specific areas under this theme include emissions, transport and pollution abatement. Data collection and advanced modelling will aid in informing policy actions and AQ management systems. However, the main challenge in these research fields is not collection of the individual data sets, or development of certain modelling systems, but rather in the management of the research outputs and ensuring continuity and growth of successful outputs, together with the development of a national knowledge base and communication platform.

This document also contributes towards the research objectives set forward under theme 3 of the EPA 2014–2020 research strategy (Climate solutions, transition management and opportunities) – in particular, the promotion of cross-disciplinary analysis of effective options for behavioural change in business and households. While previous and current research outputs may often be at the cutting edge of science, the EPA strategy recognises a need to bring together diverse research outputs to form a coherent picture of analysis for Ireland.

Much of this research also intersects with the sustainability pillar and this discussion document considers research under the themes of resource efficiency, health and well-being, ecosystem services and socio-economic aspects of a sustainable environment.

There is little doubt that, to achieve the aims and objectives set out in the EPA research strategy, and to contribute to and benefit from research on an international level, capacity development should be a central consideration of the climate change research programme in the medium term. Linkages between research projects, both within and across research institutions, must be fostered and research outputs must be communicated in a manner that encourages follow-on work. Furthermore, the development and maintenance of a knowledge base will ensure that investments in both blue-sky and more applied research projects are fully realised.

3 Methodology

Several approaches were used to gather information to inform this review, including a literature review, a review of EPA-funded research, a review of European FP7 and Horizon 2020 research projects, and semi-structured interviews with leading researchers in the air science field.

Firstly, all recently completed and ongoing EPA research activities were reviewed and a database of projects was created. Projects funded on a European scale were also reviewed as to their objectives, methods and project partners.

A combination of interviews and online questionnaire surveys were carried out to establish research gaps in the air science field as identified by leading research institutes in Ireland. These were structured primarily around the following framing questions:

1. Provide details of both EPA- and non-EPA-funded research in the air science field ongoing or recently completed.
2. What are the main knowledge gaps in the air science field in Ireland currently?
3. In your research field specifically, what do you see as the next steps?
4. How can future research integrate with current strategy?

In addition to this discussion document, this work also gave rise to the following outputs:

- A database of EPA research projects relevant to the air science theme. This database includes a brief summary of each research project, a link to the final report (if available) and the contact details of the corresponding project partner.
- A database of research funded under the EU FP7 or Horizon 2020 programmes. This database has been developed using the European Commission's CORDIS public repository. The database includes details of project partners, project abstracts and links to project websites. It also includes a field for quick determination of any Irish participants.

4 Research Priorities

This section sets out the general research areas that have been identified as requiring further work. Many of these research areas are interrelated and would benefit from an integrated approach. Capacity development and the building of international links will aid in achieving many of the aims set out.

4.1 Research Directions

The following charts and tables provide an overview of the air science research required in Ireland based on the outcomes of this review. Additional information under each heading is available in Appendix 1 and a list of suggested research projects is contained in Appendix 2, with accompanying text on the proposed research approach.

Figure 4.1 gives suggested future research directions for bioaerosols, volatile organic compounds (VOCs), black carbon (BC), PM and persistent organic pollutants (POPs). Figure 4.2 describes the need for the establishment of an AQ modelling advisory group to advance the development of a multipurpose modelling framework for Ireland. Figure 4.3 presents suggested research directions under broader sectoral headings.

4.2 Socio-economic Policy Research

With targets established for climate and air, and interim targets in place, there is a pressing need to move towards practical socio-economic policy research that offers government well-researched policy intervention options that can contribute towards compliance.

Bioaerosols	• Further research utilising the Irish Atmospheric Simulation Chamber (IASC) • Improved source term understanding • Emission rates • Relationships with particulate matter • Health impacts • Background concentrations
Nitrogen Oxides (NOx)	• The synergistic and isolated effects of NO_2 on health • Modelling and forecasting
Ammonia (NH_3)	• Potential impacts of nitrogen deposition under current agricultural food strategies • Expansion of NH_3 monitoring network
Volatile Organic Compounds (VOCs)	• Contribution to tropospheric ozone • Biogenic versus anthropogenic VOC emission contributions • Influence of biogenic VOCs in urban areas • Industrial VOC emissions and odours in urban areas
Black Carbon/Brown Carbon (BC)	• Improve understanding of relationship between optical and chemcial measurements of BC • Towards the development of an emissions inventory for BC • BC emissions from mobile sources and effecitve control measures • Source apportionment of BC
Particulate matter (PM)	• Conditions leading to peak PM concentrations • Nucleation of UFP • Continue to support updates on SOA modelling/ formation • Better quantification of non-exhaust road emissions and cooking aerosols • Potential impacts on PM levels due to EU/wider scale changes in PM levels
Persistent Organic Pollutants (POPs)	• Identify sources of dioxins, track pathways and ultimate deposition • Assess health burden and work retrospectively through process of bioaccumulation and uptake • Develop a targeted POP sampling campaign • Quantify the influence of BC on POP behaviour - POP/OC soil sampling

Figure 4.1. Future research directions for specific pollutant groups. OC, organic carbon; SOA, secondary organic aerosol; UFP, ultrafine particles.

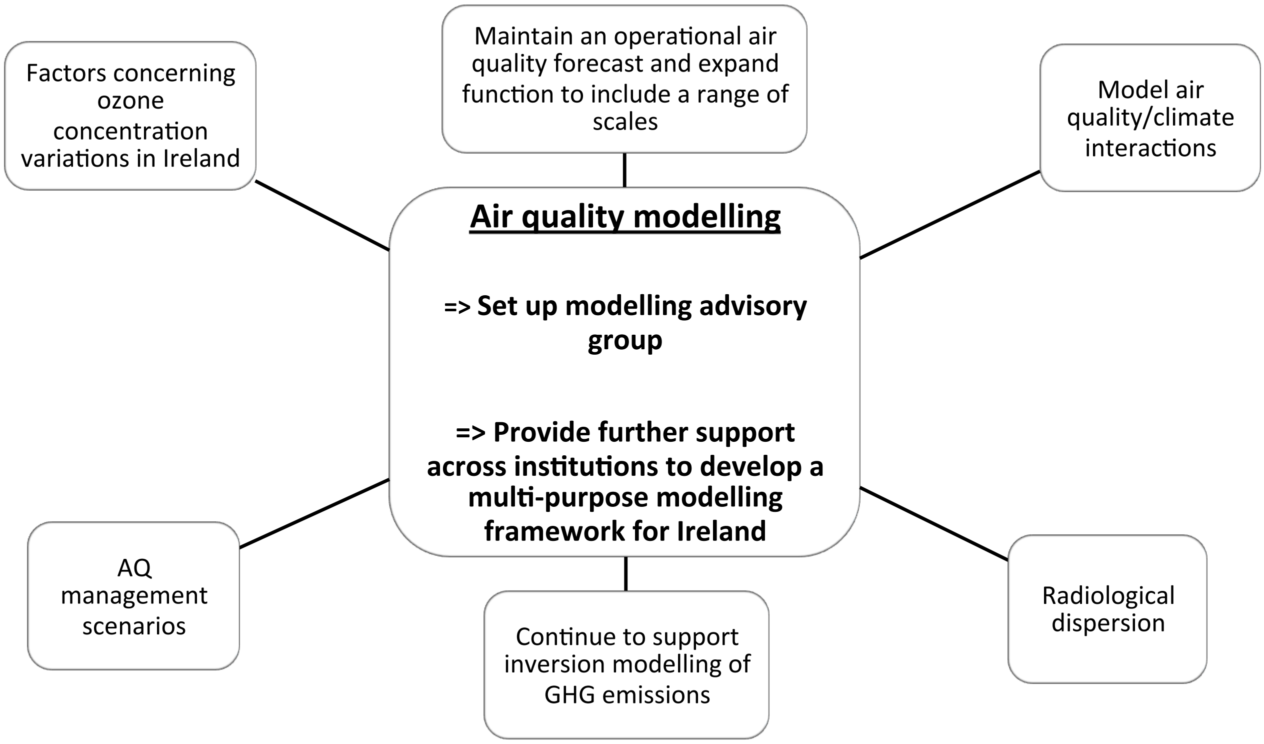

Figure 4.2. AQ modelling development research requirements. GHG, greenhouse gas.

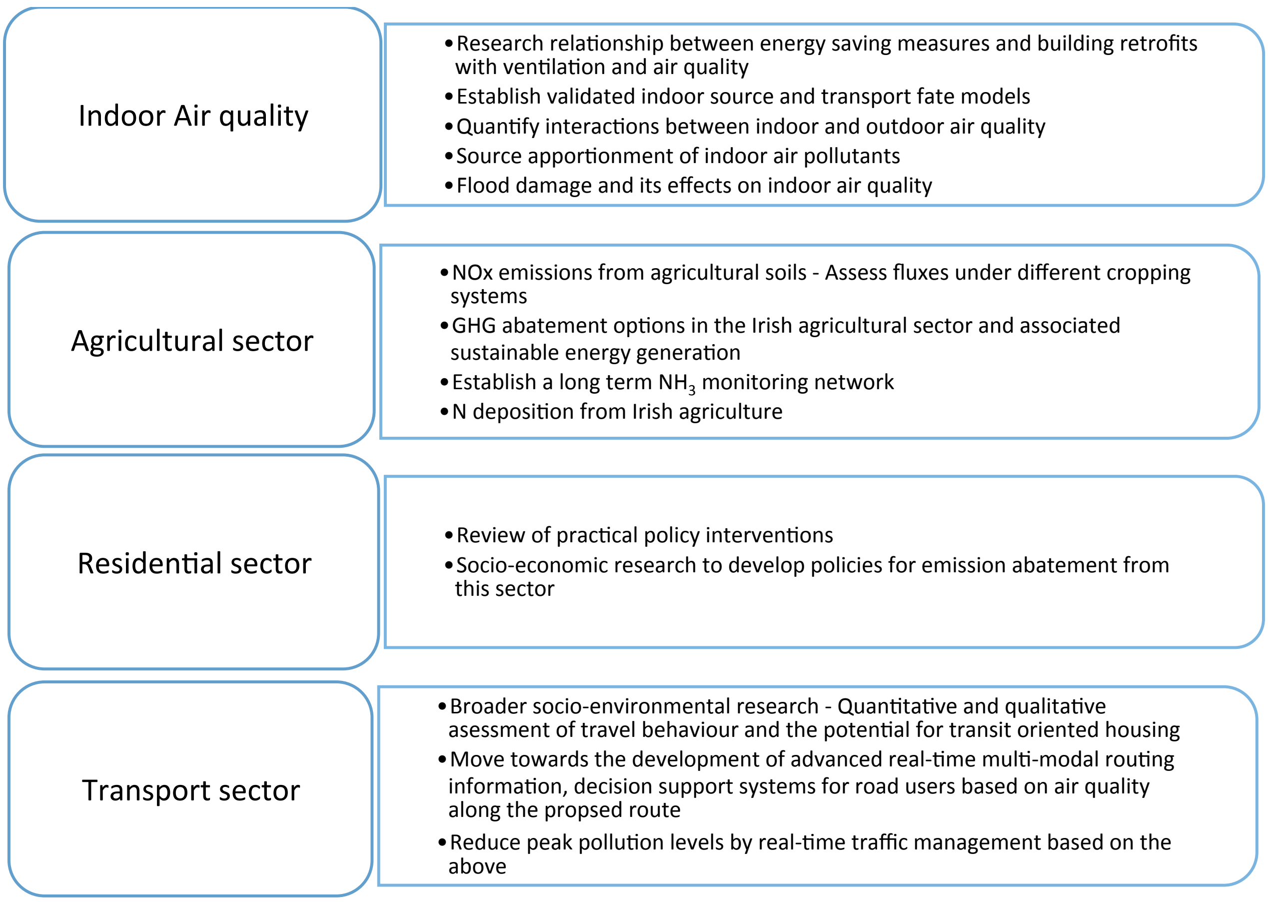

Figure 4.3. General research directions in certain sectors. GHG, greenhouse gas; N, nitrogen.

The Greenhouse gas–Air Pollution Interactions and Synergies (GAINS) and other models offer considerable value in terms of framing the issues, assessing interactions, considering the scale of impacts and macro-management. However, actual policy change requires very specific and tailored socio-economic policy research that considers, in a more flexible format, factors such as behavioural economics and elasticities, employment and political constraints, access to capital and financial modelling. There is a need for research funding bodies to select individual sectors and targets, and to challenge the research community to devise detailed policy plans that can contribute to compliance and that can be sold to both the relevant policy stakeholders and those who will be required to act (i.e. the public).

Ireland has recently negotiated ambitious abatement targets for air pollutants to 2030. In a number of cases there is no clear pathway to compliance, and in other cases there are potential changes to inventory (e.g. in respect of VOCs) and industry plans (e.g. Food Wise 2025 and NH_3) that may exacerbate the compliance challenge. There is a need for research that compiles a variety of potential activity and policy pathway scenarios to simultaneously investigate climate and air outcomes that can achieve compliance (and indeed to perhaps convey the seriousness of the challenge to the relevant sectoral bodies). This work must also include an understanding of the flexible mechanisms available in both climate and air contexts and the penalty risks associated with compliance failure.

4.3 People and Air Quality

Air pollution science has been very technologically focused and, as a result, EU and national policy interventions have been technology-driven. To achieve long-term and sustainable ‘clean’ air we need to recognise that technology alone will not get us there. There is a need to bring individual and societal activities and practices, supported by robust quantifiable science, into mainstream air pollution/carbon management so that future quantifiable policy interventions can consider not only technological but also behavioural change. An example in this field is the recently-awarded Horizon 2020 CLAiR-City project, which applies the latest social-science thinking to the source apportionment of air pollution emissions and concentrations, carbon emissions and health outcomes, in order to attribute them not just by technology but by citizens’ behaviour and daily activities. There is scope to explore relationships between AQ and individual/societal behaviours:

- We need to better understand how and where we use our cars, what our energy behaviours are, and what our consumption patterns are, in order to generate a better geography of pollution (AQ and carbon). This will allow for more targeted interventions.
- We need to better understand the relationships between AQ and social deprivation, to explore challenges around issues such as environmental justice. Public engagement and science communication must be core deliverables.

As such, a review of the existing social science evidence base and subsequent commissioning of new research to provide information on issues should be carried out, including awareness and attitudes towards air pollution among different groups, factors that influence behavioural change and evaluation of different types of intervention.

5 Research Approaches in Air Science

Most EPA-funded research projects have been of relatively short duration (mainly doctoral, postdoctoral and medium-scale studies). This short duration, coupled with limitations on maximum time scales and no guarantee of follow-on funding, means that the projects can be relatively limited in their goals. Understandably, the EPA is reluctant to invest large amounts of money on extensive projects that are not guaranteed to achieve the deliverables as set out in the project scope. However, there are ways in which the EPA could potentially minimise risks of non-completion through more involved management and development of in-house expertise. Furthermore, it is possible to simulate the broader research goals of large-scale projects without becoming too reliant on a single project. Synergies between research projects should be exploited and, in order to do this effectively, communication between researchers and across institutional boundaries should be improved upon. Increasing the effective length of a given research strand would have benefits to research outputs in the air science field.

Air science research in Ireland is generally a secondary research area. Consider, for example, some of the research institutes and the departments therein that have carried out or are carrying out research in the field of air science:

- Trinity College Dublin (TCD) – Department of Civil, Structural and Environmental Engineering
- National University of Ireland, Galway (NUIG) – Department of Physics
- University College Cork (UCC) – Department of Chemistry
- Dublin Institute of Technology (DIT) – School of Physics
- University College Dublin (UCD) – School of Mechanical and Materials Engineering

This means that air science researchers tend to come from a broad variety of backgrounds. In itself, this can benefit research, as different fields of expertise can be utilised to solve specific research questions, and the range of experience on offer should mean that novel approaches are offered to different problems. At present, however, it may be something of a hindrance to efficient integration and synergy across institutions. A great deal of the research is currently carried out by postdoctoral research fellows (as part of a postdoctoral research fellowship or as a member of a research team on a small- or medium-scale study). However, even though these are often the researchers most directly involved in the technical aspects of the research, they are not always invited to be part of steering committees for other research projects. There would be benefits in involving research fellows in relevant steering groups; improved communication will mean that they are far more likely to follow up on collaborations and integrate into different research projects.

6 Potential Research in Air Science Sub-themes

Research under the air science theme is broad and, to further improve integration of research projects, it would be useful to establish sub-themes. Using these sub-themes, working groups could be set up and regular workshops organised. A number of sub-themes are suggested below:

1. AQ modelling

   AQ models are an essential tool for managing AQ. Model development in Ireland has been somewhat fragmented between different institutions and future research under this sub-theme should tie previous research together and build on existing modelling algorithms. Some fields of research under this sub-theme would include:

   - developing advanced PM schemes, improved understanding of secondary organic aerosol (SOA) formation;
   - atmospheric processing of VOCs and contributions to tropospheric ozone;
   - evaluation of impacts of changes in energy and transport systems on AQ;
   - atmospheric ammonia modelling and nitrogen deposition;
   - developing a multi-purpose modelling framework to predict AQ at national and local scales, which can be used for a range of purposes including routine forecasting, exposure assessments, scenario analysis and AQ management.

2. AQ monitoring and emerging techniques, emissions and measurements

   Improving national AQ requires in-depth knowledge on levels of various pollutants across the country. The best possible measurement techniques are required, and types and levels of pollutants being emitted by various sources need to be understood in detail. Some of the fields of research under this sub-theme would include:

   - developing national monitoring capacity (e.g. NH_3 network, targeted POP sampling);
   - evaluation of new technologies to monitor air pollution, including high-resolution site-specific monitors, low-cost portable sensors and remote sensing technology;
   - BC measurement research, including studies of how particles absorb and scatter light;
   - developing and improving emissions inventory for all criteria pollutants;
   - developing and using techniques to better understand the composition of pollutants.

3. Health and environmental effects of air pollution and indoor air pollution

   There is a vast amount of research linking pollutants to various health problems. Research under this sub-theme would contribute to further understanding the role of air pollution on health and the environment. Although regulations target outdoor air pollution levels, people spend the majority of their time indoors and indoor AQ could also be a major contributor to health issues. While this area is outside the direct remit of EPA research, it is implicitly connected to outdoor AQ and transport-related themes, and may be addressed in part by future EPA research activities. The substantial health effects coupled with these crossovers mean that, while it may be carried out by external parties, it is still important to consider the required research areas in this field as part of this review. Some fields of research under this theme would include:

   - developing air pollution exposure models that account for indoor and outdoor exposure to individual and multi-pollutants;
   - further understanding of links between health effects and exposure to specific pollutants;
   - identification of at-risk populations and developing solutions to reduce impacts of pollutant exposure;
   - measurement and modelling of indoor AQ and assessing building design and outdoor environmental effect on indoor AQ.

4. Air pollution and climate change

   AQ can be affected by a changing climate, and climate change can also be influenced by air pollution. Short-lived climate pollutants (SLCP) are particularly relevant to the air science theme. These pollutants have a relatively short lifetime in the atmosphere and include BC, CH_4, tropospheric ozone and hydrofluorocarbons (HFCs). Research under this theme would include:

- improving understanding of interactions between anthropogenic and natural air pollutants;
- investigating the effects of BC on climate and the gains to be achieved by reducing source emissions with high BC to organic carbon ratios;
- understanding the influence of climate change on PM formation and lifecycle;
- understanding the role of VOCs in the formation of tropospheric ozone;
- assessing impacts of AQ on renewable energies (e.g. biomass);
- evaluation of costs, benefits and risks of adaptation.

7 Key Findings and Recommendations

The key findings of this review of the current state of air science research in Ireland are given below. Further details of specific research areas and possible projects are included in the appendices.

1. Improvements in regular and reliable AQ monitoring are required. Such data are necessary for continued improvements in AQ models. This may include the operation and management of non-statutory monitoring networks to provide data on concentrations and depositions of a range of pollutants. It may also include the calculation of resultant health and ecosystem indicators to monitor trends (including data for national statistics), as well as emergent air pollution threats and sources, and to provide data for public information and research purposes.
2. Currently, there is poor quantification of organic aerosol pollutants and a general lack of knowledge on air pollution source apportionment. The SAPPHIRE and AEROSOURCE projects are a start to addressing this issue, but it is likely to require continued attention.
3. The number of operational aerosol mass spectrometers should be increased.
4. An independent modelling advisory group should be established to oversee modelling activities, including the development and use of new modelling tools and model inter-comparison activities.
5. Project steering committees are not currently used to their full advantage, and one recommendation is that there should be increased involvement of postdoctoral research fellows on steering committees for projects aside from their own.
6. There are many EU air science projects that Irish researchers are not involved in. The EPA should encourage Irish universities to be more involved by facilitating workshops to bring relevant people together. The establishment of research sub-themes would help in this regard. Researchers should be encouraged to join any relevant sub-groups and contribute to and attend workshops as required. Suggested sub-themes are as follows:
   - AQ modelling;
   - AQ monitoring and emerging techniques, emissions and measurements;
   - health and environmental effects of air pollution and indoor air pollution;
   - air pollution and climate change.
7. There would be significant interest from air science researchers in Ireland in an open research call from the EPA. This would foster greater innovation within the research community. Many of the research projects are very specific in their nature; while this is clearly necessary in some cases, an open call would encourage novel projects to help address major challenges in air science. An open call could be linked with the sub-themes identified above. An important aspect of submissions should be that they build on previous funded research.
8. The current specific research calls are often budgeted for a postdoctoral researcher or doctoral student only. There is a need for larger-scale projects that could permit major research teams in Ireland to work together in a more interdisciplinary approach.
9. Research strategy timeframes have been too short. Inability to guarantee follow-on projects means that research projects are often quite limited in their goals.
10. Social science and AQ research should become more integrated to achieve sustainable clean air. Future policy interventions will need to consider behavioural change together with technological change, and research must seek to understand the links between AQ and societal behaviour.

Specific recommendations include:

- Develop a complete *multi-purpose modelling framework* and establish a *modelling advisory committee*. This advisory committee should be set up in the near future so that it can influence and inform the direction of the emissions inventory development fellowship.
- Establish types, size variability and properties of *bioaerosols* in Ireland, their interaction with other

pollutants, climate impacts and human health effects.

- Undertake research to further our understanding of how the outdoor environment and new, more energy-efficient building design affects *indoor AQ*.
- Undertake research to improve understanding of the *organic aerosol* fraction in $PM_{2.5}$ and PM_{10}, and to quantify SOAs and associated interactions, leading towards the development of sophisticated organic PM modelling frameworks.
- Develop a *targeted POP sampling campaign* leading towards better quantification of emissions in Ireland.
- Undertake optical and chemical measurements of BC and brown carbon (BrC), from both fresh and aged emissions, and quantify relationships. Provide the basis for *developing robust emissions inventory data for BC* and contribute to information on the impact of BC on climate properties.

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Abbreviations

AM	Active mobility
AQ	Air quality
BC	Black carbon
BrC	Brown carbon
CAFE	Clean Air for Europe
CH_4	Methane
CO	Carbon monoxide
COH	Coefficient of haze
DIT	Dublin Institute of Technology
EPA	Environmental Protection Agency
ESFRI	European Strategy Forum on Research Infrastructure
EU	European Union
FP7	Seventh Framework Programme for Research and Technological Development
GHG	Greenhouse gas
IAQ	Indoor air quality
IASC	Irish Atmospheric Simulation Chamber
NO_x	Nitrogen oxides
NUIG	National University of Ireland, Galway
OC	Organic carbon
PAH	Polycyclic aromatic hydrocarbons
PM	Particulate matter
POP	Persistent organic pollutant
SO_2	Sulfur dioxide
SOA	Secondary organic aerosol
TCD	Trinity College Dublin
UCC	University College Cork
UCD	University College Dublin
UFP	Ultrafine particles
VOC	Volatile organic compound
WHO	World Health Organization

Appendix 1 Specific Research Areas

A1.1 Specific Pollutants

A1.1.1 Bioaerosols

Bioaerosols (pollen, spores, bacteria, etc.) can affect human health and also play a role in climate (e.g. ice nucleation). However, very little is known about their nature and occurrence in Ireland. To provide a more robust dispersion modelling system for bioaerosols and subsequent regulation of sources, the following knowledge gaps need to be filled:

- better quality emission rates for main sources;
- improved understanding of source term;
- improved understanding of background concentrations;
- improved understanding of relationships with PM;
- improved understanding of health implications.

The Irish Atmospheric Simulation Chamber (IASC) is a new national facility designed to support world-leading research activities in the key strategic areas of atmospheric and materials science. Based at UCC, the IASC facility will consist of a large custom-built chamber equipped with cutting-edge instrumentation to enable innovative studies on air pollution and climate change. It will also serve as an advanced testbed for novel atmospheric monitoring techniques, emerging sensor technologies and depolluting materials. The facility aims to promote new research synergies and increase Irish competitiveness in the European Research Area, while also impacting strongly on the environment, health and the economy in Irish society.

A1.1.2 Ammonia

Under the Food Harvest 2020 strategy, atmospheric emissions of ammonia are predicted to increase. There is currently no long-term gaseous ammonia monitoring capacity in the EPA background atmospheric monitoring network. Research in this area should contribute towards the expansion of existing NH_3 monitoring networks, with a particular focus on emissions from agriculturally intensive regions. This research can build on the EPA Ammonia2 project (2012 CCRP-MS8), which provided recommendations for an optimised national monitoring network for Ireland, and on the EPA AmmoniaN2K project (2013-EH-MS-14), which will establish emissions and ambient monitoring programmes. Assessment of the impacts of the Food Harvest 2020 strategy on atmospheric ammonia and potential impacts on natural ecosystems will be required in the development of a suitable network. It is well established that nitrogen deposition is one of the leading threats to biodiversity. In Ireland, 80% of total nitrogen deposition is from ammonia (mainly from agricultural emissions). There has been limited assessment of the impacts of current food strategies on atmospheric nitrogen and potential impacts on natural ecosystems. Evaluation of the influence of proposed food strategies on atmospheric ammonia, nitrogen deposition and potential impacts are now required.

A1.1.3 Volatile organic compounds

VOCs are precursors of the formation of secondary pollutants, including tropospheric ozone, nitrates and SOAs. However, the nature of VOCs is poorly understood in Ireland because very few measurements have been made. A number of important research questions therefore arise:

- To what extent do VOCs contribute to levels of tropospheric ozone?
- What is the relative importance of biogenic versus anthropogenic emissions of VOCs in Ireland?
- Do biogenic emissions influence AQ in urban areas?
- What VOCs are emitted by industrial installations, and do they affect local AQ (e.g. ENVA odour/AQ issue)?

Strategic funding allocation in this area would enable Ireland to be part of Europe-wide research infrastructure (EUROCHAMP) and part of the European Strategy Forum on Research Infrastructures (ESFRI) roadmap. The ESFRI is a strategic instrument to develop the scientific integration of Europe and to strengthen its international outreach. As the organisation responsible for overseeing environmental research in Ireland, the EPA research programmes should issue calls for research that capitalise specifically on significant investment by Science Foundation Ireland (SFI).

A1.1.4 Nitrogen oxides

In recent times there has been a strengthening of the linkage between nitrogen dioxide (NO_2) exposure and adverse health effects (including that of diminished life expectancy) (Hesterberg *et al*., 2009; WHO, 2013). Recent reviews of epidemiological studies provide some evidence that NO_2 exposure may decrease lung function and increase the risk of respiratory symptoms (Hesterberg *et al*., 2009; WHO, 2013) and may also affect those members of society at risk, i.e. the very young and old, those with asthmatic symptoms and those with cardiological problems (O'Connor *et al*., 2008; Taj *et al*., 2016). Indeed the prevalence of asthma and allergy, defined as immunologically mediated hypersensitivity, is increasing. It is estimated that over 20% of the world's population suffers from IgE-mediated allergic diseases, including allergic asthma, allergic rhinitis, allergic conjunctivitis, atopic eczema/atopic dermatitis and anaphylaxis. Much of the ambient work done to date has highlighted the fact the NO_2 is generally accompanied by many other air pollutants. The potential synergistic interaction between ultrafine PM and NO_2 has recently been treated as suspect (Karthikeyan *et al*., 2013). Recognising these pressures, the US EPA, the WHO and the UK Committee on the Medical Effects of Air Pollutants (COMEAP) have begun to mount research-led initiatives to fully ascertain these associations and quantitatively evaluate the potential effect NO_2 may have on human health. Indeed, each of the aforementioned parties has commissioned reports focusing on this area. To ensure Ireland is at the forefront of this trend it is important that we establish our own country-specific drivers and vulnerabilities for this pollutant.

Emission sources of NO_x are another area in need of further research. Agricultural soils are a known source of NO_x, which contribute to the formation of ozone and $PM_{2.5}$, and subsequently to transboundary air pollution. It is estimated that 20 to 30% of the world's NO_x emissions are produced in soils by microorganisms, but their contribution to Ireland's NO_x emissions is unknown. NO_x fluxes from various cropping systems need to be established and soil emissions of NO_x from irrigated agricultural land estimated. To better understand both NO_x's health effects and its spatial variation, modelling must be undertaken as discussed in Appendix 2. To improve the quality of local AQ models, it will be necessary for Ireland to develop tools to promote the use of earth observation data sets. The transport sector is a major source of NO_x and, to better manage this source, research focused on developing advanced real-time multi-modal routing information and decision-support systems for road users, based on AQ on proposed route, will be beneficial.

A1.1.5 Black carbon/brown carbon

Increasing pressure to reduce emissions of BC and PM from diesel vehicles necessitates an expansion in the measurement of real-world emission rates, in order to assess vehicle deterioration over time. Increasing focus on BC due to its strong warming potential would require further research as to actual emission rates and contributions. Furthermore, there is evidence to suggest that BC is a more useful proxy for traffic exhaust than PM_{10}. It may therefore be more useful to use BC as an indicator for measuring the effects of AQ mitigation measures on ambient AQ levels than PM_{10}. Reche *et al.* (2011a) found that concentrations of elemental BC reproduce road traffic (exhaust) variability on an hourly level across various European regions (irrespective of mean BC levels and whether the stations are representative of traffic emissions or urban background). A characteristic daily pattern with morning and evening maxima coincident with traffic rush hours was evident at all sites. BC has been found to be governed mostly by vehicle exhaust emissions, while PM_{10} is also affected by non-exhaust particulate emissions suspended by traffic, other non-traffic emissions and atmospheric dilution (Reche *et al*., 2011b). NO_2/BC, CO/BC and organic carbon (OC)/BC ratios vary widely as a result of distance to emission source, type of emission source and vehicle fleet composition.

There is a need for research to advance our understanding of the relationship of optical and chemical measurements of BC and BrC from both fresh and aged emissions. This understanding will ultimately provide the basis for developing robust emissions inventory data for BC and BrC and will supply important information on the impact of ageing on aerosol properties relevant to the climate.

Understanding BC emissions and concentration variations will assist in reducing overall BC levels. Reducing levels is directly beneficial in terms of human health and, for sources with high BC/OC ratios, a quick gain can be observed in terms of climate change abatement.

A1.1.6 Particulate matter, organic aerosol formation and climate implications

Research on PM to reduce uncertainties is the most effective way to reduce concentrations of and exposure to PM and associated health impacts, through furthering our understanding of the following:

1. the strength and role of sources of primary and secondary PM in Ireland;
2. SOA formation – Ireland needs to further develop and provide multiple tools for modellers to address the complex problem of modelling SOA formation. Organic aerosols are a significant component of $PM_{2.5}$ across Ireland. The sources and processes that form SOAs are the focus of several research projects (SAPPHIRE etc.). Increasing our knowledge of the processes associated with SOAs (i.e. sources and mechanisms of SOA formation) will improve $PM_{2.5}$ modelling;
3. concentrations of PM_{10} and $PM_{2.5}$ at urban, urban background and rural sites in different parts of Ireland under average and episode conditions;
4. the impact on PM_{10} and $PM_{2.5}$ concentrations at Irish sites of changes in emissions of primary PM and precursor gases at Irish, EU and wider scales;
5. poorly quantified emission sources, including non-exhaust road transport emissions and cooking aerosols, and processes such as resuspension from roads;
6. the chemical processes that lead to the transport and formation of PM, and our ability to model the relationships between particle composition and sources, including the development of markers for particular emission sources;
7. nucleation of ultrafine particles (UFPs) and its role in particulate formation.

High PM_{10} and $PM_{2.5}$ events have been frequently observed in towns around Ireland in recent years. In addition to ongoing source apportionment work there is a need to analyse the precise nature of these episodes, in order to properly represent them in model simulations and to develop appropriate control strategies. Increasingly stringent PM target and limit values, together with the known health impacts, mean that knowledge of the conditions that lead to elevated concentrations is of utmost importance. While we know the general conditions that lead to high PM events, we in Ireland are not currently in a position to model such events deterministically (in advance) with a high degree of accuracy. While some of this is due to inadequacies in the emissions inventory, this is not the only contributory factor. For the purpose of public health information and the development of control strategies, there is a need to develop a greater understanding of PM formation and, in particular, a risk-based model module that can anticipate high events using the emissions data (to be developed).

Interactions of biogenic VOCs with nitrate (NO_3) radicals (formed from anthropogenic NO_2 and ozone) represent a direct method of positively linking anthropogenic and biogenic emissions. NO_3 radicals affect PM formation and composition over its lifetime, but the effects will vary depending on relative humidity, particle type (acidity) and the fate of the peroxy radical. To further understanding of SOA formation and to foster improvement of simulations in models, additional data are required on nitrate oxidation pathways and photochemical as well as dark ageing.

A1.1.7 Persistent organic pollutants

There is limited monitoring of POPs in the Irish environment (air, soil and water). Sensitive ecosystems and protected habitats, such as Natura 2000 sites, could potentially benefit from increased monitoring. Further development of an inventory, which should involve additional monitoring and research regarding POP emissions from various sources (e.g. peat burning, sewage sludge, waste disposal) is required.

Public awareness regarding POPs – including health and environmental effects of POPs and alternatives – is relatively low. There is a need to provide public information and training of workers, scientists, educators and technical personnel. How best to promote and facilitate such awareness programmes should be researched.

In order for Ireland to reduce exposure of the population to dioxins, a greater understanding of the sources and pathways that most significantly contribute to human risk is required. As such, research is required to link dioxin sources to population exposure. This will be most effectively achieved by carrying out both a top-down and a bottom-up assessment:

- Identify sources of dioxin compounds and track their pathways and ultimate deposition.
- Begin with human health burdens and work backwards through the process of bioaccumulation and uptake.

Together these separate investigations will provide a greater understanding of the life cycle of dioxins in our environment. The ELEVATE research project (2015-HW-MS-4) represents a good start here. It is important that the capacity building outlined in the proposed research project is adhered to. This study focuses on polybrominated diphenyl ethers (PBDEs), hexabromocyclododecanes (HBCDDs) and perfluorooctane sulfonate (PFOS) in indoor environments, but it is the human exposure pharmacokinetic modelling that could contribute to future air science research and, in particular, to working backwards from human health burdens towards sources of POP emissions.

Limitations in the spatial variability in POP concentration measurements have been noted in a number of studies (Bogdal *et al*., 2013). The current EMEP measurement network is not sufficient to capture variations. Passive samplers could be used to gather more data on POP concentrations (Halse *et al*., 2011). This could be coupled with trajectory modelling (e.g. Flexpart) to examine likely sources.

A1.2 Modelling Research

A1.2.1 Air quality modelling and a multi-purpose modelling framework

Decision-makers rely on results from AQ models to provide predictions of future air pollution levels, for use in developing the necessary AQ plans and emission reduction strategies (also providing the scientific foundation for AQ policies). Continued funding is required to improve Ireland's AQ modelling systems. The methods by which this will be achieved include enhanced input data, refinements to chemical modelling mechanisms and improved modelling algorithms.

AQ modelling is an important tool for developing and evaluating AQ policy. The models can be used for assessing compliance with EU directives and to inform negotiations on policy changes. Models provide a wider assessment of the state of AQ across Ireland, in terms of both airborne concentrations and potential human exposure, and of the deposition of acidifying and eutrophying pollutants. Ireland requires advanced air pollution models that contain atmospheric chemistry and advanced PM schemes.

Many of the aforementioned research areas are necessary for developing Ireland's AQ modelling capabilities. The broad applications of models and the broad range of expertise required to develop a complete system means that a strategic view needs to be taken regarding research in this area.

The development of Ireland's modelling capacity cannot be achieved by isolated research projects. Rather, there is a need for a *modelling advisory group*, which will oversee the development of a modelling system that can meet a range of different requirements. It is important that the models used are fit for purpose, are not extended beyond their capabilities and are capable of incorporating relevant advances and innovation in modelling capability. It is also important that there is dialogue and interaction between the modelling community and the EPA/local councils/other stakeholders, and also that model capability is well understood.

Various research institutions and personnel have different skills in relation to AQ modelling, and model development in Ireland should proceed by utilising all of these skills. Modelling aspects that need to be considered include (but are not limited to) the following:

- large scale hemispheric transport and deterministic modelling;
- local scale street modelling (e.g. street canyons);
- chemical modelling;
- source apportionment and receptor modelling;
- statistical and probabilistic modelling;
- field measurements, monitoring and sample analysis.

A comprehensive modelling system for Ireland will require interaction between all of these fields. With the coming development of more advanced emission inventories to drive national-scale AQ models, the opportunity to develop a *multipurpose modelling framework* should be considered (e.g. WRF-CHEM-FLEXINVERT). Research project 2015-CCRP-MS.26 will be integral to building this modelling framework. Such a framework would be capable of addressing several research topics and emergency response scenarios:

- air quality forecasting on a variety of scales;
- air quality and climate interactions;
- volcanic ash forecasting;
- radiological dispersion;
- greenhouse gas (GHG) inversion modelling of emissions;
- air quality management scenario analysis;
- factors controlling ozone concentrations in Ireland.

A1.3 Research Directions for Certain Sectors

A1.3.1 Indoor air quality

Since a large proportion of the population might spend up to 90% of their time indoors, the quality of indoor air is very important for population health and well-being. In contrast to outdoor AQ, indoor AQ (IAQ) is not regulated by enforceable air standards (due to the privacy of indoor spaces). The Scientific Committee on Health and Environmental Risks (SCHER) supports the development of health-based guideline values and, in this context, indicators other than concentrations of pollutants may also be applicable (e.g. ventilation rate, dampness). Outdoor AQ measurements cannot predict indoor levels due to the influence of numerous local factors, including building airtightness and air flows.

Difficulties relating to policies in IAQ mean that this topic has been somewhat neglected in international research. Traditionally IAQ has been seen as more of an issue in the developing world (e.g. with wood-burning stoves), but prevention of the health effects of poor IAQ is required in all regions in the world. There is a need to develop guidelines, specific to Irish environmental conditions, on how to promote, develop and maintain clean air in homes and offices. This is especially relevant in the wake of the increased prevalence of zero-energy buildings. Efforts to reduce GHG emissions and fuel consumption have led to the development of guidelines to lower resource consumption in buildings. Such guidelines are clearly necessary but they have a negative side effect in lower building ventilation rates. This in turn can lead to poorer IAQ. Further work is required to understand the effects of ambient environment on building control. Such work should necessarily account for the ambient environment. There is potentially a public health risk associated with poor management of such buildings.

Previous EPA-funded research has assessed the effects of energy retrofits on thermal comfort, occupant behaviours and IAQ, and a desk study commenced (March 2016) which will produce a literature review to determine the effect of retrofit ventilation modifications on radon concentrations in buildings. A knowledge gap remains in our understanding of the nature of the relationship between energy saving measures, such as building retrofits, and ventilation levels associated with IAQ. The Sustainable Energy Authority of Ireland (SEAI) funded a short project in 2014 that carried out simulations using the IAPPEM probabilistic IAQ model to determine the effect of ventilation rates on indoor PM concentrations (McGrath *et al*., 2014). Further research is needed to validate this model, including comparison with detailed monitoring data and also assessment of other common substances, including benzene, CO, formaldehyde, naphthalene, NO_2, polycyclic aromatic hydrocarbons (PAH), radon, trichloroethylene and tetrachloroethylene.

Key areas that require further work in an Irish context are:

1. Identification and validation of existing indoor source and transport fate models. This modelling would include PM_{10}, $PM_{2.5}$, UFPs, benzene, CO, formaldehyde, naphthalene, NO_2, PAH, radon, trichloroethene and tetrachloroethene, and would also consider factors such as ozone terpene chemistry (study of toxicology of ozone-initiate reaction mixtures). It is generally unknown whether some indoor air pollutants act as surrogates for UFPs (or vice versa).

2. Modelling the interaction between indoor and outdoor air. This would involve combining larger-scale modelling work with IAQ modelling. Research questions include: how is airflow indoors (and AQ) affected by larger-scale air flow and air pollution levels? Can building design and/or building management be adjusted depending on outdoor AQ?

3. Source apportionment of pollutants in an indoor environment in quantitative terms.

The EU project IAQSense will be delivering a full IAQ sensing system by project completion (end of 2016). The availability of reliable and reasonably priced sensing systems will facilitate these research fields.

A1.3.2 Agricultural sector

In Ireland GHG emissions associated with food and agriculture make a substantial contribution to national emissions totals. The EU FP7 project (PURGE) has shown that modifying diets in the UK to comply with WHO dietary recommendations (for health) would achieve a 17% reduction in GHG emissions, while also saving approximately 7 million years of life lost prematurely over the next 30 years (London School of Hygiene and Tropical Medicine, 2014). Reducing consumption of animal products and soft drinks and increasing consumption of fruit, cereals and vegetables are methods given for reducing GHG emissions further.

Further research is likely to be developed through the Agri-Research Expert Advisory Group's programme, Stimulating Sustainable Agricultural Production through Research and Innovation (SSAPRI). On-farm mitigation measures are a potential source of research via the rural development programme 2014–2020. Such research should be linked to broader environmental impacts and consideration given to the effects of changing agricultural emissions on the following broader AQ areas:

1. Modelling N_2O emissions from agricultural soil. Previous model results indicated that the N_2O fluxes vary greatly among different crops and are affected by site-specific environmental factors such as soil properties and weather conditions, as well as management practices. The new 2015-CCRP-FS.22 project (analysis of grasslands and associated management practices and potential impact on GHG emissions and removals) should begin to address this issue.
2. NO_x emissions from agricultural soils. Agricultural soils are a known source of NO_x, which contribute to the formation of ozone and $PM_{2.5}$, and subsequently to transboundary air pollution. It is estimated that 20 to 30% of the world's NO_x emissions are produced in soils by microorganisms, but their contribution to Ireland's NO_x emissions is unknown. NO_x fluxes should be measured from various cropping systems and soil emissions of NO_x from irrigated agricultural land estimated.
3. Ammonia and GHG abatement options in the Irish agriculture sector.
4. Establishment of a long-term ammonia monitoring network.
5. Nitrogen deposition from the agricultural sector.

A1.3.3 Residential sector

The residential fuel use market is not yet fully understood and further research is necessary to develop the policies to manage climate and air emissions. *Census 2016* (CSO, 2016) and other data sets will afford an excellent opportunity to analyse the make-up of this sector, changes during the last 5 years, and targets for policy actions to address climate and air emissions from this sector. This work should be spatially referenced and should draw upon multiple national data sets [Central Statistics Office (CSO) Building Energy Rating (BER) and Household Budget Survey (HBS) data].

The residential sector will (on current projections) be the dominant national source of PM emissions into the future. Associated with this, there is a need for increasingly refined socio-economic research that is focused on analysing and developing policies to address emissions from this sector. This work requires an in-depth assessment of what a practical policy intervention would be – with attention to economic considerations, employment impacts, health impacts and barriers to change. Furthermore, the tensions between climate (bioenergy) policy and air outcomes (health impacts, target breaches) should be recognised in this research.

A1.3.4 Transport sector

There remains a need to improve the calibration of AQ models and traffic simulation models so that the transport network can be optimised in order to improve local AQ. Additional sensor monitoring is required on a large scale, as is model forecasting of emission levels and detailed mapping of AQ. Research in this field should have the following long-term broad objectives:

1. developing tools to promote the use of earth observation data sets to improve the quality of local AQ models;
2. developing advanced real-time multi-modal routing information, and decision-support systems for road users based on AQ on proposed routes;
3. reduced peak pollution levels through real-time management and positive impact on population health.

These broader objectives will be achieved by building on a number of related projects. There is a need for more refined research on estimated national-scale fleet emissions (not individual vehicle testing), which takes account of road types, vehicle types, loads, vehicle locations, usage patterns and so forth. The 2016 POWSCAR data will again afford opportunities to update work in this context. Vehicle fleet evolution should then be modelled to see what emission outcomes can be expected, with scenarios involving alternative fleet mixes. Buses form a major component of Dublin's public transport network and their routing should take AQ into consideration. With the development of detailed AQ maps of the Dublin region, the effects of different routing patterns should be assessed with the objective of incorporating such information into AQ management plans.

Policy research should address practical policy interventions that can achieve a desired mix in the vehicle fleet. In essence, there is a need to evaluate the existing incentives and factors that guide fleet evolution and determining the adjustments or new policies that can alter fleet evolution to a preferred pathway. Consideration of the expected evolution of fleet technology options over the next decade is also recommended. The expected policy mechanisms could include Vehicle Registration Tax/Motor Tax changes, Fuel Tax changes, transport priority incentives and so forth.

In Ireland we need to develop and facilitate active mobility (AM, i.e. walking and cycling in combination with public transport use). Cycling has seen a significant increase in popularity in Dublin in recent years and some work has been carried out regarding increasing cycle lane provision. AM promotion is required and policymakers, practitioners and researchers should take note of the results of the EU-funded PASTA (Physical Activity through Sustainable Transport Approaches) research project. This project will produce a compendium of good practices for AM promotion.

Appendix 2 Suggested Research Projects

Suggestions for research projects include:

1. field and simulation chamber-based research to advance understanding of bioaerosols in Ireland and interrelated effects;
2. the role of VOCs in the formation of secondary pollutants including tropospheric ozone, nitrates and SOAs;
3. towards the development of an emissions inventory for BC and BrC – an accounting framework;
4. measurement of BC emissions from trucks, treatment devices and degradation rates;
5. source apportionment of BC before and after fleet composition changes;
6. developing a risk assessment model for high PM events;
7. nucleation of UFPs, SOA formation and the role of nitrate radicals and hydroxyl (-OH) radicals in the aerosol life cycle;
8. source apportionment of PM exposure;
9. flood damage and its effects on IAQ;
10. oxidative chemistry and its role in indoor air pollution;
11. expansion of ammonia monitoring capacity – establishment of a long-term monitoring development of a targeted POP sampling campaign;
12. potential impacts of nitrogen deposition under current agricultural food strategies;
13. quantifying the influence of BC on POP behaviour – POP/OC soil sampling;
14. quantitative and qualitative assessment of travel behaviour and potential for transit-oriented housing.

A2.1 Project 1: Field and Simulation Chamber-based Research to Advance Understanding of Bioaerosols in Ireland and Interrelated Effects

Field measurements using the latest instrumentation are required to investigate types, size, variability and properties of bioaerosols. This would ultimately lead to a better understanding of the effects of anthropogenic activities on levels of bioaerosols. Results from such measurements could then be used to quantify their influence on health and climate.

The interaction of bioaerosols with pollutant gases is poorly understood. Use of the simulation chamber will allow changes in gas/aerosol composition and associated chemical and physical properties to be continuously monitored.

It will thus be possible to investigate the interaction of bioaerosols with pollutant gases (e.g. NO_2, ozone, VOCs, NH_3, etc.). This would help address questions over the influence of man-made emissions on the properties of the particles that can affect health and climate.

Study size: medium-scale study

A2.2 Project 2: The Role of VOCs in the Formation of Secondary Pollutants Including Tropospheric Ozone, Nitrates and Secondary Organic Aerosols

A number of field measurement campaigns should be conducted in urban, semi-urban and rural areas to help understand the influence of VOCs. High-time resolution measurements are required to identify sources and their variability. The relationship between certain VOCs and PM, NO_2 and other pollutants could be investigated. A source apportionment study combining VOCs, gases and PM constituents should be performed.

Detailed information on the kinetics and mechanisms for the atmospheric oxidation of VOCs is essential for understanding their role in the formation of ozone and SOAs. This information is best obtained from simulation chamber studies carried out under a variety of conditions. Ireland will soon be equipped with a world-class atmospheric simulation chamber. It is ideally suited to support research programmes that investigate oxidation of biogenic and anthropogenic VOCs, identify the reaction products and enable mechanisms to be constructed for use as parameters in AQ and some climate models. This type of work could link with field measurements of precursor VOCs and the chemical composition of ambient PM. Simulation chamber studies can also provide valuable information on the chemical and optical properties of SOAs, which can affect health and climate.

Study size: medium-scale study

A2.3 Project 3: Towards the Development of an Emissions Inventory for Black and Brown Carbon – an Accounting Framework

There is a need for research to advance our understanding of the relationship of optical and chemical measurements of BC and BrC from both fresh and aged emissions. This understanding will ultimately provide the basis for developing robust emissions inventory data for BC and BrC and will supply important information on the impact of ageing on climate-relevant aerosol properties.

The overall goal of this work would be to develop a framework and supporting data to quantitatively account for the contributions of source emissions and atmospheric processing to the radiative absorption by carbonaceous aerosols in the atmosphere, ultimately contributing towards the development of an emissions inventory. Three major steps are required to reach this goal:

1. assess the nature and origin of BC in Ireland (2015-CCRP-PhD-2);
2. quantify the relationships of the optical and chemical properties of the major components of light-absorbing carbon in the emissions from key air pollution sources (e.g. diesel engines, incomplete coal combustion, biomass burning);
3. study how these relationships evolve during atmospheric processing and transport.

This work would require molecular marker source apportionment tools, as well as the measurement of aerosol optical properties, to provide a mechanism to quantitatively determine the source contributions to light-absorbing carbon. The work would likely require direct measurements of the emissions of dominant light-absorbing carbon sources with field measurements in both urban and background locations to understand the influence of sources and atmospheric ageing on aerosol light absorption. By targeting key sources of light-absorbing carbon it should be possible to map the association of chemical components of primary emissions with optical properties.

A2.4 Project 4: Black Carbon Emissions from Trucks, Treatment Devices and Degradation Rates

The next step in this research field will be the identification of potential sampling sites (based on the TCD study investigating the impact of air pollution from diesel vehicles in Ireland). Additional sampling campaigns of individual emission rates should then be carried out at these locations to measure BC, CO, NO_x and PM. This new work could use truck identification technology to capture licence plate numbers. In this manner it would be possible to assess degradation rates and also the success/failure of any after-treatment devices that are applied to vehicles. Emissions inventories will be upgraded as a result. This research should fill in temporal and spatial gaps in emissions data for HGV diesel emissions and also address the issue of degradation, thereby improving the quantification of diesel emission for Ireland as a whole.

A2.5 Project 5: Source Apportionment of Black Carbon Before and After Fleet Composition Changes

The EPA research programme should continue to address operational source apportionment, particularly for organics. The AEROSOURCE project makes a good start in addressing this shortcoming but an expansion of the number of operational mass spectrometers is required. In addition to traffic exhausts, biomass burning activities are one of the primary sources of BC emissions.

A2.6 Project 6: Developing a Risk Assessment Model for High Particulate Matter Events

The first stage of this work would involve analysis of historical AQ data from the monitoring network. Key episodes would be selected for analysis using meteorological data together with detailed emissions inventory data (to be developed as part of 2015-CCRP-MS.26). Basic conceptual models should be developed for each of the episodes.

It is necessary to examine emission sources and patterns together with chemical processes and meteorological conditions that lead to elevated PM events in detail. Selected episodes should be modelled using an advanced AQ model and emissions inventory (e.g. CMAQ). Model performance in capturing these events should be quantified. Updates to the chosen model should be investigated based on these results and the outcome of the research should be an improved understanding of the meteorological and chemical pathways that contribute to high PM formation. A research project in this field should result in an AQ model module for *risk assessment* regarding high-PM events and/or improvements in PM emissions inventory.

Study size: small-scale study

A2.7 Project 7: Nucleation of Ultrafine Particles, Secondary Organic Aerosol Formation and the Role of Nitrate Radicals and OH in the Aerosol Life Cycle

The conversion of volatile organic gases from gas to particles through reactions with oxidants such as ozone, OH and NO_3 is a global, natural process responsible for the formation of biogenic secondary aerosols (i.e. SOAs). These aerosols are a factor in cloud formation but details of this process are not well understood. Therefore, the project would investigate how atmospheric conditions control the number of nucleation events. This will require data sets on new particle formation events. Processes take place at the size level of less than 3 nm and at concentrations between 0.01 and 0.1 ppt (parts per trillion). Work carried out in Finland has shown that the number of nucleation days/year varies between 60 and 120. For molecules with very low volatility, clustering precedes condensational growth. Low volatility products may initiate growth by reacting with other precursors. Improved understanding of these mechanisms is relevant for SOA formation from anthropogenic emissions from organic components. With lower mass emissions of PM in the coming years, nucleation will become a more prevalent source of UFPs.

Research in this field should link gas phase chemistry to SOA formation using the IASC (or similar). Under varying atmospheric conditions (e.g. relative humidity and temperature) and using different particulate seeding densities, SOA formation should be examined. The aim would be to experimentally quantify the effects of NO_3 radicals on organic aerosol over its lifetime. The study would account for SOA formation. The research should also consider an experimental comparison of effects under photochemical (OH) and dark conditions (NO_3). The end result will be an improvement in understanding of SOA formation and an improved ability to model SOA formation.

Study size: medium-scale study.

A2.8 Project 8: Source Apportionment of Particulate Matter Exposure

Ongoing and recently completed research projects focus on source apportionment of PM in urban and rural areas in Ireland. A natural next step in this research (and building on the EU research project TRANSPHORM) is to link source apportionment with exposure assessment and carry out a source exposure assessment. This should include PM_{10}, $PM_{2.5}$, elemental carbon, *particle number count* (PNC) and benzo[*a*]pyrene (BaP). Such work will allow targeted emission reduction policies and management strategies to be implemented.

A2.9 Project 9: Flood Damage and its Effects on Indoor Air Quality

There is a case for collecting information on harmful emissions in water-damaged buildings. Flooding is a common and emotive issue in Ireland, and compounds from decomposing building material (moisture initiated chemical degradation) can contribute to toxicity (Bornehag *et al*., 2005). Association of adverse health effects with water damage and mould in buildings has been repeatedly shown in epidemiological studies, but the causative factors are not fully understood. There are many types of emissions from microbial growths, including spores, vegetative cells, submicron-size fragments and toxins. Although the association between moisture problems and adverse health effects has been demonstrated, the causative agents are not well defined. However, studies have indicated that renovating the building either decreases or eliminates the symptoms. There are particular species of bacteria and fungi that are detected in damp environments at higher than 'normal' levels. However, previous research suggests that not all dampness is equally harmful (Nevalainen and Seuri, 2005).

A2.10 Project 10: Oxidative Chemistry and its Role in Indoor Air Pollution

The move towards energy-efficient housing has influenced the ventilation of houses. In Ireland construction design and other site specific phenomena will act together with local climate to affect ventilation patterns in new-build and older houses. Infiltration of photochemical oxidants from ambient air is a key concern. Modelling work in Ireland to date has focused mainly on sources and transport of pollutants indoors and through buildings.

Residential field studies are required to assess ozone, NO_x, VOCs, PM compositions and other reactive oxygen species together with relevant building information (e.g. building types, air exchange rates). Human behaviour (window opening, etc.) must also be considered. Indoor measurements should be used to quantify non-uniform distributions of pollutants in homes that are both naturally and centrally ventilated. Existing indoor source and transport fate models can be improved using these results. This work should benefit from the data from the IAQSense project, which is due for completion in 2016.

A2.11 Project 11: Expanding Ammonia Monitoring Capacity – Establishment of a Long-term Monitoring Network

Under the Food Harvest 2020 strategy, atmospheric emissions of ammonia are predicted to increase. There is currently no long-term gaseous ammonia monitoring capacity in the EPA background atmospheric monitoring network. This project would expand existing monitoring at the EPA and Met Éireann stations to include ammonia (with a minimum addition of monthly ammonia passive samplers). The network should also look at establishing additional stations to capture emissions from intensive agricultural regions. This network would be informed by the results from the Ammonia2 project (2012 CCRP-MS8), which provided recommendations for an optimised national monitoring network for Ireland, and by the AmmoniaN2K project (2013-EH-MS-14), which will establish emissions and ambient monitoring programmes.

A2.12 Project 12: Potential Impacts of Nitrogen Deposition Under Current Agricultural Food Strategies

This research project would involve assessment of the Food Harvest 2020 project impacts on atmospheric ammonia and potential impacts on natural ecosystems. It is well established that nitrogen deposition is one of the leading threats to biodiversity. In Ireland, 80% of total nitrogen deposition is from ammonia (mainly from agricultural emissions). There has been limited assessment of the impacts of current food strategies on atmospheric nitrogen and potential impacts on natural ecosystems. The objective of this proposed project would be to evaluate the influence of proposed food strategies on atmospheric ammonia and nitrogen deposition, and to assess potential impacts using a critical loads approach. This project would build upon and integrate results from the AmmoniaN2K project (2013-EH-MS-14), which will quantify impacts of ammonia from intensive pig and poultry agriculture on Special Areas of Conservation (SACs) and Special Protection Areas (SPAs) in Ireland. This proposed project would be dependent on an increase in ammonia monitoring capacity in Ireland, based on the Ammonia2 project (2012 CCRP-MS8).

Study size: medium-scale study.

A2.13 Project 13: Primary Organic Aerosol Volatility

The primary organic aerosol (POA) emitted from petrol and diesel-fuelled vehicles should be studied at atmospherically realistic concentrations so as to improve the AQ models that inform AQ standards for $PM_{2.5}$.

This research should assess the proportion of particle emissions that are elemental carbon (which will not evaporate in the atmosphere), semi-volatile or effectively non-volatile, and how emissions compare during cold start and/or hard accelerations.

A2.14 Project 14: Quantitative and Qualitative Assessment of Travel Behaviour and Potential for Transit-oriented Housing

Many of Ireland's cities suffer from major traffic congestion. Research in this field would be aimed at assessing ways in which GHG impacts could be reduced by placing affordable housing in transit-oriented development. There is a suggestion that placing public transport users near public transport has a GHG benefit over placing higher-income car-owning households near public transport (Cervero, 2007).

There is a need to evaluate quantitative travel behaviour in conjunction with qualitative research on health, well-being and impact on residents. Such research should evaluate travel demand reduction benefits together with economic effects, health and well-being of residents in affordable housing projects in cities in Ireland.

Research in this area would provide valuable data for urban planners and housing departments, and would provide information relevant to longer-term strategies for reducing GHG emissions.

Appendix 3 Black Carbon Assignment as a Particulate Matter Fraction from Diesel Engines

The following review gives an indication of previous research to assess BC emissions from diesel engines in order to assess whether it can be assigned as a PM fraction.

A 1996 study in California measured emission rates for PAH and BC from light- and heavy-duty vehicles (Miguel *et al.*, 1998). Heavy-duty diesel trucks emitted 1440 ± 160 mg of fine BC particles per kg of fuel burned. Light-duty vehicles emitted 30 ± 2 mg of fine BC particles per kg of fuel burned. A study in India (during a truck strike) concluded that the removal of diesel trucks from the roads resulted in a significant reduction in ambient BC levels (Latha *et al.*, 2004). On the day the strike started there was a sudden decrease in BC concentrations. On subsequent days, BC continued to decrease although more gradually as a result of the finite residence time of BC. Concentrations were found to decrease from an average pre-strike level of 58 $\mu g/m^3$ to a minimum of 2 $\mu g/m^3$ (8 days after the trucks were withdrawn). Another study in India during a nationwide truck strike in 2009 found a 57% reduction in ambient BC (Sharma *et al.*, 2010). Levels fell from 60–70 $\mu g/m^3$ pre-strike to 20–30 $\mu g/m^3$ during the strike. Levels continued to fall gradually thereafter.

In the USA, a long-term study found that a continuous increase in diesel fuel consumption in the San Francisco Bay Area between the 1960s and early 2000s was accompanied by a decrease in BC concentrations by a factor of three (Kirchstetter *et al.*, 2008). The reductions in BC reflect improved engine technologies, emissions controls and changes in diesel fuel consumption. This study highlights the need for ongoing BC measurements so that such changes can be better correlated with BC reductions. A study carried out over a 30-year period in New Jersey, USA, found that trucking density was strongly correlated with coefficient of haze (COH) (Davis *et al.*, 2010). This correlation was found to increase from 0.2 in the time period 1971–1978 to 0.65 in the time period 1997–2003. The correlation between unemployment rate and COH, in contrast, was found to decrease from –0.27 to –0.01 over the same period. Their model explained almost half of the variability in COH levels using economic activity levels, environmental regulations and weather characteristics.

Invernizzi *et al.* (2011) found that within city proximal areas in Milan, different traffic intensities were associated with different BC levels. BC was measured at three different locations, on an outer road with no traffic restrictions, on an intermediate road subject to a congestion traffic charge where pre-Euro 4 standard cars require a ticket and finally on the pedestrian zone where no cars are permitted. A sharply declining BC gradient was observed from the outer to the inner zones. Interestingly, mean PM_{10}, $PM_{2.5}$ and PM_1 concentrations did not show significant differences between the traffic zones. The ratio of BC to PM_{10} decreased by 47% and 62%, respectively, in the eco-pass and pedestrian zones compared with the outer zone. This study showed that BC is a very useful metric for demonstrating the effectiveness of AQ mitigation measures.

Lambe *et al.* (2009) used chemical mass balance and positive matrix factorisation models to investigate the sources of BC in Pittsburgh. 67% of BC was described by the diesel factor. The gasoline (or petrol) factor accounted for 20% of BC. However this study did not measure fleet composition so inferences cannot be drawn about relative contributions. Low vehicle speed during a stop-go traffic set-up appear to result in lower BC concentrations when compared with higher free-flowing speeds (Holder *et al.*, 2014).

BrC is a light-absorbing particulate organic compound. The distribution of BrC in the atmosphere is largely unknown, as are its importance relative to BC and its influence on direct radiative forcing by aerosols. Some work has been carried out using aircraft sampling over the USA to assess the BrC absorption in solvent extracts of particulate filters. BrC was observed throughout the tropospheric column and its prevalence relative to BC increased with altitude, which indicates contributions from secondary sources (Liu et al., 2014). The study concluded that BrC is an important component of direct aerosol radiative forcing.

This review generally concludes that significant monitoring of BC will be required in Ireland and recommends that a BC emissions inventory should developed.

AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL

Tá an Ghníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaol a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ó éifeachtaí díobhálacha na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialú: *Déanaimid córais éifeachtacha rialaithe agus comhlíonta comhshaoil a chur i bhfeidhm chun torthaí maithe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.*

Eolas: *Soláthraímid sonraí, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, spriocdhírithe agus tráthúil chun bonn eolais a chur faoin gcinnteoireacht ar gach leibhéal.*

Tacaíocht: *Bímid ag saothrú i gcomhar le grúpaí eile chun tacú le comhshaol atá glan, táirgiúil agus cosanta go maith, agus le hiompar a chuirfidh le comhshaol inbhuanaithe.*

Ár bhFreagrachtaí

Ceadúnú

Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaol:

- saoráidí dramhaíola *(m.sh. láithreáin líonta talún, loisceoirí, stáisiúin aistrithe dramhaíola)*;
- gníomhaíochtaí tionsclaíocha ar scála mór *(m.sh. déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta)*;
- an diantalmhaíocht *(m.sh. muca, éanlaith)*;
- úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe *(OGM)*;
- foinsí radaíochta ianúcháin *(m.sh. trealamh x-gha agus radaiteiripe, foinsí tionsclaíocha);*
- áiseanna móra stórála peitril;
- scardadh dramhuisce;
- gníomhaíochtaí dumpála ar farraige.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil

- Clár náisiúnta iniúchtaí agus cigireachtaí a dhéanamh gach bliain ar shaoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
- Maoirseacht a dhéanamh ar fhreagrachtaí cosanta comhshaoil na n-údarás áitiúil.
- Caighdeán an uisce óil, arna sholáthar ag soláthraithe uisce phoiblí, a mhaoirsiú.
- Obair le húdaráis áitiúla agus le gníomhaireachtaí eile chun dul i ngleic le coireanna comhshaoil trí chomhordú a dhéanamh ar líonra forfheidhmiúcháin náisiúnta, trí dhíriú ar chiontóirí, agus trí mhaoirsiú a dhéanamh ar leasúchán.
- Cur i bhfeidhm rialachán ar nós na Rialachán um Dhramhthrealamh Leictreach agus Leictreonach (DTLL), um Shrian ar Shubstaintí Guaiseacha agus na Rialachán um rialú ar shubstaintí a ídíonn an ciseal ózóin.
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Uisce

- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uiscí idirchriosacha agus cósta na hÉireann, agus screamhuiscí; leibhéil uisce agus sruthanna aibhneacha a thomhas.
- Comhordú náisiúnta agus maoirsiú a dhéanamh ar an gCreat-Treoir Uisce.
- Monatóireacht agus tuairisciú a dhéanamh ar Cháilíocht an Uisce Snámha.

Monatóireacht, Anailís agus Tuairisciú ar an gComhshaol

- Monatóireacht a dhéanamh ar cháilíocht an aeir agus Treoir an AE maidir le hAer Glan don Eoraip (CAFÉ) a chur chun feidhme.
- Tuairisciú neamhspleách le cabhrú le cinnteoireacht an rialtais náisiúnta agus na n-údarás áitiúil *(m.sh. tuairisciú tréimhsiúil ar staid Chomhshaol na hÉireann agus Tuarascálacha ar Tháscairí)*.

Rialú Astaíochtaí na nGás Ceaptha Teasa in Éirinn

- Fardail agus réamh-mheastacháin na hÉireann maidir le gáis cheaptha teasa a ullmhú.
- An Treoir maidir le Trádáil Astaíochtaí a chur chun feidhme i gcomhair breis agus 100 de na táirgeoirí dé-ocsaíde carbóin is mó in Éirinn.

Taighde agus Forbairt Comhshaoil

- Taighde comhshaoil a chistiú chun brúnna a shainaithint, bonn eolais a chur faoi bheartais, agus réitigh a sholáthar i réimsí na haeráide, an uisce agus na hinbhuanaitheachta.

Measúnacht Straitéiseach Timpeallachta

- Measúnacht a dhéanamh ar thionchar pleananna agus clár beartaithe ar an gcomhshaol in Éirinn *(m.sh. mórphleananna forbartha)*.

Cosaint Raideolaíoch

- Monatóireacht a dhéanamh ar leibhéil radaíochta, measúnacht a dhéanamh ar nochtadh mhuintir na hÉireann don radaíocht ianúcháin.
- 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 cosanta ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Faisnéis Inrochtana agus Oideachas

- Comhairle agus treoir a chur ar fáil d'earnáil na tionsclaíochta agus don phobal maidir le hábhair a bhaineann le caomhnú an chomhshaoil agus leis an gcosaint raideolaíoch.
- Faisnéis thráthúil ar an gcomhshaol ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaol (*m.sh. Timpeall an Tí, léarscáileanna radóin).*
- Comhairle a chur ar fáil don Rialtas maidir le hábhair a bhaineann leis an tsábháilteacht raideolaíoch agus le cúrsaí práinnfhreagartha.
- Plean Náisiúnta Bainistíochta Dramhaíola Guaisí a fhorbairt chun dramhaíl ghuaiseach a chosc agus a bhainistiú.

Múscailt Feasachta agus Athrú Iompraíochta

- Feasacht chomhshaoil níos fearr a ghiniúint agus dul i bhfeidhm ar athrú iompraíochta dearfach trí thacú le gnóthais, le pobail agus le teaghlaigh a bheith níos éifeachtúla ar acmhainní.
- Tástáil le haghaidh radóin a chur chun cinn i dtithe agus in ionaid oibre, agus gníomhartha leasúcháin a spreagadh nuair is gá.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil

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

- An Oifig um Inmharthanacht Comhshaoil
- An Oifig Forfheidhmithe i leith cúrsaí Comhshaoil
- An Oifig um Fianaise is Measúnú
- An Oifig um Cosaint Raideolaíoch
- An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag comhaltaí air agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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State of Play of Air Science Research in Ireland: Discussion Document

Authors: Aoife Donnelly, Bruce Misstear, Brian Broderick and Francesco Pilla

Climate - Water - Sustainability

Identifying pressures • Informing policy • Developing solutions

Effective decision making relies on the communication of relevant evidence-based monitoring, research and analysis. Within the EPAs air pollution research programme there is a wealth of information which has arisen from the analyses of air quality, environmental, health and policy data. This report identifies a way forward to enhance engagement with stakeholders with an interest in such information including the EPA and other policy makers at a national level. There is scope to further improve the impact and applicability of historical, ongoing and future research activities. The focus of this report is on priority pollutants in relation to local air quality outlined in the CAFÉ Directive, and short-life climate drivers and contributory species.

Identifying Pressures

Past and ongoing Environmental Protection Agency (EPA) research activities related to air quality in Ireland have been analysed through a combination of structured interviews, meetings and analysis of review documents. Whilst there is a strong body of research now available, there is scope for improving the effectiveness of research further, providing support for adaptation planning and greater exploitation of synergies between Irish, European and international work. Through this, stronger linkages can be established between environmental research programmes in the humanities and the natural sciences.

Informing Policy

There is an important role for government/state actors in supporting air science research that is policy focussed. In particular, such research can be important in supporting a clean air strategy. Bringing the relevant state actors and academics together will help ensure research is policy focused. Facilitating researchers to become members of steering committees on other relevant research projects could help develop research capacity and inform researchers of government and policy research needs.

Developing Solutions

The report recommends that bringing the relevant state and academic actors together in a co-ordinated fashion will optimise policy focussed research. In this regard, it is recommended that sub-themes within the air science field be established to maximise synergistic research impacts. Suggested sub-themes are: (1) air quality modelling (to include the establishment of a modelling advisory committee); (2) air quality monitoring and emerging techniques, emissions and measurements; (3) health and environmental effects of air pollution and indoor air pollution; and (4) air pollution and climate change. Various research directions are suggested in the report and, furthermore, an open research call from the EPA is recommended as a means to foster innovation and a more interdisciplinary approach within the research community. Capacity development will be required to achieve maximum benefit from research on national and international levels and, moreover, to achieve the aims and objectives set out in the EPA's research strategy. Central to this will be the development and maintenance of a knowledge base and the communication of research outputs in a manner that facilitates follow-on work.

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