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Unconventional Gas Exploration and Extraction (UGEE) Joint Research Programme

Final Report 3: Baseline Characterisation of Air Quality

Authors: Dawn Keating and Rob Saikaly

Ambient air quality monitoring sampling intake

CDM Smith
British Geological Survey NATURAL ENVIRONMENT RESEARCH COUNCIL
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On the 23rd of July 2016, the Department of Communications, Energy and Natural Resources (DCENR) became the DCCAE. Along with a name change, the new Department incorporates functions that were formerly held within the Environment Division of the DECLG. The Department retains responsibility for the Telecommunications, Broadcasting and Energy sectors. It regulates, protects, develops and advises on the Natural Resources of Ireland. Of particular relevance is the role of the Petroleum Affairs Division (PAD) to maximise the benefits to the State from exploration for and production of indigenous oil and gas resources, while ensuring that activities are conducted safely and with due regard to their impact on the environment and other land/sea users. The Geological Survey of Ireland (GSI) is also within DCCAE and provides advice and guidance in all areas of geology including geohazards and groundwater and maintains strong connections to geoscience expertise in Ireland.

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This Research Programme is being administered by the EPA and steered by a committee with representatives from DCCAE (formerly DCENR and the Environment Division of the DECLG), the Commission for Energy Regulation (CER), An Bord Pleanála (ABP), the GSI, NIEA, the Geological Survey of Northern Ireland (GSNI), as well as a Health representative nominated by the Health Service Executive (HSE).

UGEE Joint Research Programme

Environmental Impacts of Unconventional Gas Exploration and Extraction

(2014-W-UGEE-1)

Final Report 3:

Baseline Characterisation of Air Quality

by

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References to government departments (DCENR and DCELG) throughout the report use the names of these departments prior to July 2016. References to the Department for the Economy (DfE) throughout the report use the name of its predecessor, the Department of Enterprise Trade and Investment (DETI), the department responsible for petroleum licensing in Northern Ireland until May 2016.

UGEE Joint Research Programme

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Project A3 Internal Review Panel[1]

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1 More details available at:
http://www.epa.ie/pubs/reports/research/ugeejointresearchprogramme/ugeejrptasksorganisations.html

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Executive Summary

Unconventional gas exploration and extraction (UGEE) involves hydraulic fracturing ("fracking") of low-permeability rock to permit the extraction of natural gas on a commercial scale from unconventional sources such as shale gas deposits, coal seams and tight sandstone. The Environmental Protection Agency (EPA), the Department of Communications, Energy and Natural Resources (DCENR) and the Northern Ireland Environment Agency (NIEA) awarded a contract in August 2014, to a consortium led by CDM Smith Ireland Limited, to carry out a 24-month research programme looking at the potential impacts on the environment and human health of UGEE projects and operations (including construction, operation and aftercare).

The UGEE Joint Research Programme (JRP)[2] is composed of five interlinked projects and involves field studies (baseline monitoring of water and seismicity), as well as an extensive desk-based literature review of UGEE practices and regulations worldwide. The UGEE JRP was designed to provide the scientific basis that will assist regulators – in both Northern Ireland and Ireland – to make an informed decision about whether or not it is environmentally safe to allow fracking. As well as research in Ireland, the UGEE JRP looks at and collates evidence from other countries.

Project A3 (Air Quality) deals with the requirements and needs for additional air baseline monitoring (in terms of frequency, locations and the types of pollutants covered) in the context of environmental impact statements (EISs). This report (*Final Report A3*) specifically describes the work carried out under Tasks 1, 2 and 3 (see "Terms of Reference").[3]

This report seeks to address three key objectives related to each of these tasks:

- Task 1: to review existing air monitoring data, including data on naturally occurring radioactive materials (NORM);
- Task 2: to review the requirements and experience of air baseline characterisation in countries in which UGEE projects/operations have taken or are taking place;
- Task 3: to identify and make recommendations for guidelines on the extent of the air baseline monitoring (in terms of frequency, locations and the types of pollutants covered) that needs to be carried out for an environmental impact statement (i.e. on a project basis).

While Ireland has an extensive air quality monitoring network designed chiefly to comply with European ambient monitoring requirements, it was found that these data would need to be supplemented with additional monitoring data for comprehensive baseline characterisation.

A full baseline characterisation of air quality was not carried out prior to the commencement of operations in all assessed jurisdictions in which commercial UGEE operations are ongoing. In many cases, this lack of baseline characterisation prior to the commencement of UGEE activities has been highlighted as an important information gap. However, extensive studies into air quality and other environmental impacts are being carried out across almost all jurisdictions. Recommendations for baseline studies and extensive investigations into potential air quality impacts have been made as a result of many studies across all jurisdictions. As a result, Ireland is well placed to comply with international recommendations that baseline studies should be carried out, and potential impacts thoroughly assessed prior to UGEE operations, exploratory or otherwise, are carried out.

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2 www.ugeeresearch.ie

3 www.epa.ie/pubs/reports/research/ugeejointresearchprogramme/ugeeresearchrevisedtermsofreference.html

Programmes for additional ambient air quality monitoring are described for oxides of nitrogen, ozone precursors, particulate matter, benzene and non-methane volatile organic compounds, benzo[*a*]pyrene and radon.

1 Introduction

Unconventional gas exploration and extraction (UGEE) involves hydraulic fracturing ("fracking") of low-permeability rock to permit the extraction of natural gas on a commercial scale from unconventional sources, such as shale gas deposits, coal seams and tight sandstone. The Environmental Protection Agency (EPA), the Department of Communications, Energy and Natural Resources (DCENR), and the Northern Ireland Environment Agency (NIEA) awarded a contract in August 2014, to a consortium led by CDM Smith Ireland Limited, to carry out a 24-month research programme looking at the potential impacts on the environment and human health of UGEE projects and operations (including construction, operation and aftercare).

The UGEE Joint Research Programme (JRP)[4] is composed of five interlinked projects and involves field studies (baseline monitoring of water and seismicity), as well as an extensive desk-based literature review of UGEE practices and regulations worldwide. The UGEE JRP was designed to provide the scientific basis that will assist regulators – in both Northern Ireland and Ireland – to make an informed decision about whether or not it is environmentally safe to permit UGEE projects/operations involving fracking. As well as research in Ireland, the UGEE JRP looks at and collates evidence from other countries.

The environmental impacts of UGEE projects/operations considered are those arising from UGEE projects/operations in their totality, not just from fracking activities. Furthermore, all stages of UGEE projects/operations must be considered (i.e. including construction, commissioning, operation, decommissioning and aftercare, as well as off-site and other developments).

1.1 Context

Onshore Petroleum Licensing Options were awarded to Ireland in March 2011. These were preliminary authorisations to three exploration companies seeking to assess the shale gas potential within the Northwest Carboniferous Basin (NCB) and the Clare Basin. In Northern Ireland, one exploration company secured a Petroleum Licence from the Department of Enterprise, Trade and Investment (DETI) to explore the potential for shale gas reserves in County Fermanagh, within the NCB. The specific UGEE exploration areas, based on the licences that were held until recently, are shown in Figure 1.1.

In Ireland, exploration drilling, including drilling that would involve hydraulic fracturing, is not allowed under current licensing options. Nonetheless, two of the three companies have submitted applications for follow-on licences, which would include exploration drilling. The DCENR will not consider these applications further until the findings of the UGEE JRP have been published. In addition, the DCENR will not consider any applications for exploration authorisations in other onshore areas until the UGEE JRP has concluded. In Northern Ireland, the abovementioned DETI licence was terminated as the licence conditions (a "drill or drop" work programme requiring specified exploration, including drilling a stratigraphic borehole, in the first 3 years and, before the end of year 3, a commitment to drilling an exploration well within the following 2 years) were not met.

In May 2012, the EPA released the report *Hydraulic Fracturing or "Fracking": A Short Summary of Current Knowledge and Potential Environmental Impacts* from a preliminary study (Healy, 2012). This short desk study was conducted for the EPA by the University of Aberdeen and provided an introduction to the environmental aspects of UGEE projects/operations, including a review of regulatory approaches used in other countries and areas for further investigation and research.

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4 www.ugeeresearch.ie

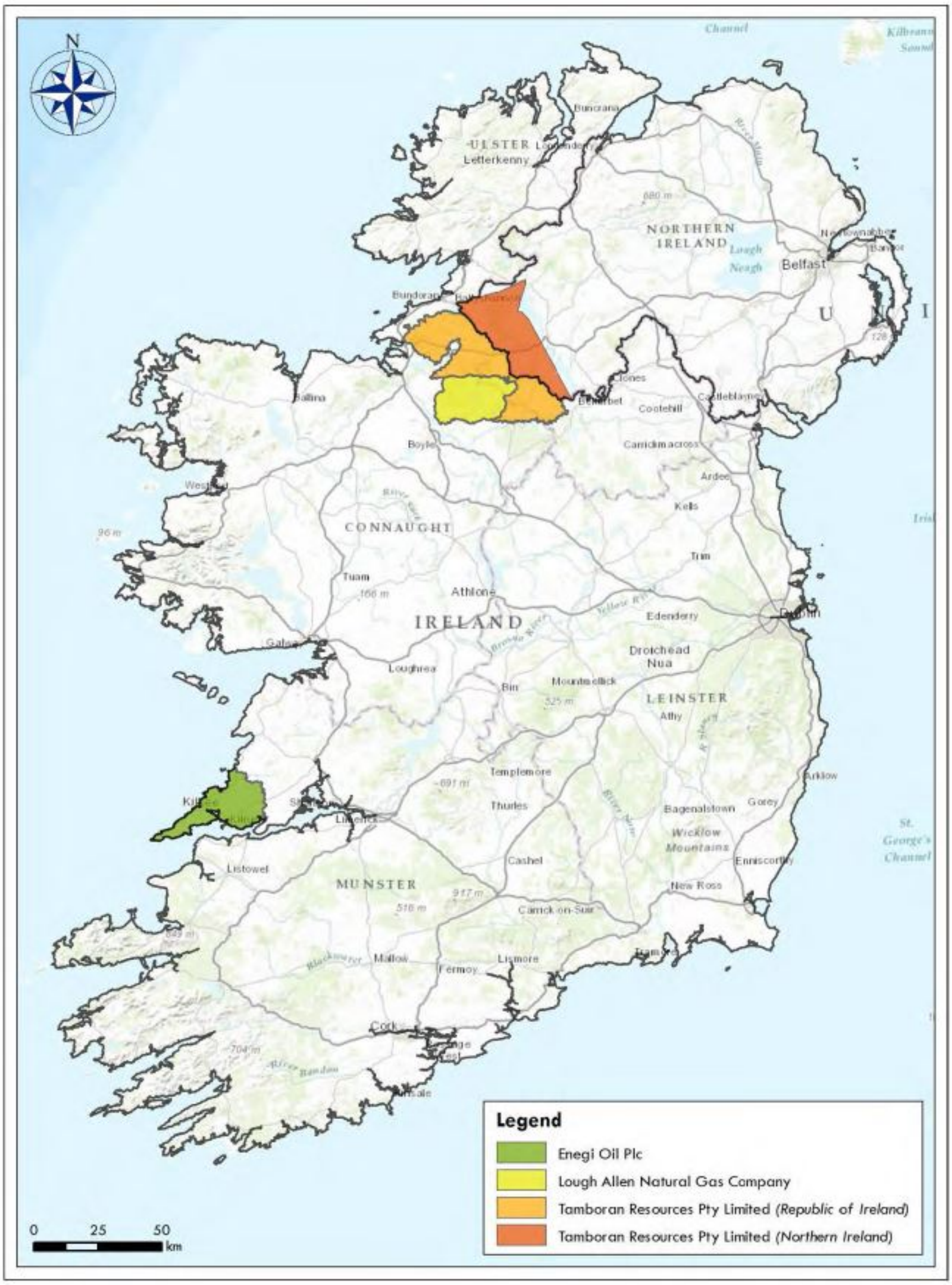

Figure 1.1. Overview of the case study areas of the UGEE JRP.

In brief, some of the key findings of this study were:

- the importance of adequate knowledge of local geology in order to assess potential impacts on groundwater quality and the possibility of induced seismic activity;
- the importance of well integrity for preventing groundwater contamination;
- the uncertainty regarding the "carbon footprint" of shale gas in comparison with conventional natural gas; this is an important issue related to climate change;
- baseline studies (of surface water and groundwater, and seismic studies) are needed before drilling begins;

- UGEE is a relatively new area of research (i.e. only a limited number of published, peer-reviewed, scientific studies are available in this area).

The information provided by this preliminary research project was used along with other sources, such as European Commission reports, to develop the "Terms of Reference" for the UGEE JRP, in order to provide a more comprehensive research programme. Between 11 January and 8 March 2013, the EPA administered a public consultation in relation to the draft "Terms of Reference" for this research programme. Submissions were assessed and relevant comments were taken into account when finalising the document.

In order to assist government bodies make informed decisions about any potential future licensing and management of UGEE projects/operations on the island of Ireland, comprehensive knowledge of the potential impacts of this process on the environment and human health is required. This knowledge will be generated from a number of sources, including research in the European Union (EU) and internationally, and through this programme of research.

The key questions to be addressed by the UGEE JRP are:

1. Can UGEE projects/operations be carried out in the island of Ireland whilst also protecting the environment and human health?
2. What is "best environmental practice" in relation to UGEE projects/operations?

The JRP is funded by the EPA, the DCENR and NIEA. It is managed by a steering committee comprising the EPA, the Department of Environment, Community and Local Government (DECLG), the DCENR, the Geological Survey of Ireland (GSI), the Commission for Energy Regulation, An Bord Pleanála, the NIEA, the Geological Survey of Northern Ireland (GSNI) and the Health Services Executive.

1.2 Overview of the Unconventional Gas Exploration and Extraction Joint Research Programme

The main aim of the UGEE JRP is to further the understanding of the potential impacts of UGEE projects/operations on the environment and human health. It comprises five separate, but interlinked, projects, as follows:

- **Baseline characterisation:**
  - Project A1 (Groundwater, Surface Water and Associated Ecosystems);
  - Project A2 (Seismicity);
  - Project A3 (Air Quality).
- **Impacts and mitigation measures:**
  - Project B: UGEE Projects/Operations: Impacts and Mitigation Measures.
- **Regulatory framework:**
  - Project C: Regulatory Framework for Environmental Protection.

Potential air emissions from UGEE projects/operations may originate from sources such as:

- trucks and drilling equipment;
- natural gas processing and transportation;
- fugitive emissions;

- evaporative emissions of chemicals from wastewater ponds;
- spills and well blow-outs;
- post-operation leakages from wells.

Project A3 (Air Quality) will assess the requirements and needs for additional air baseline monitoring (in terms of frequency, locations and the types of pollutants covered) in the context of environmental impact statements (EISs). The Environmental Impact Assessment (EIA) Directive (2011/92/EU) refers to the following impacts on air: air quality (pollutants, suspended particles); odour; noise; and vibration and radiation. Existing sources of air pollution will be identified, and the components of any existing air pollution will also be identified and quantified. The potential emissions covered include, but are not limited to, those monitored under the EIA Directive.

This report (*Final Report A3*) covers Tasks 1, 2 and 3 of Project A3, which comprises the tasks shown in Figure 1.2.

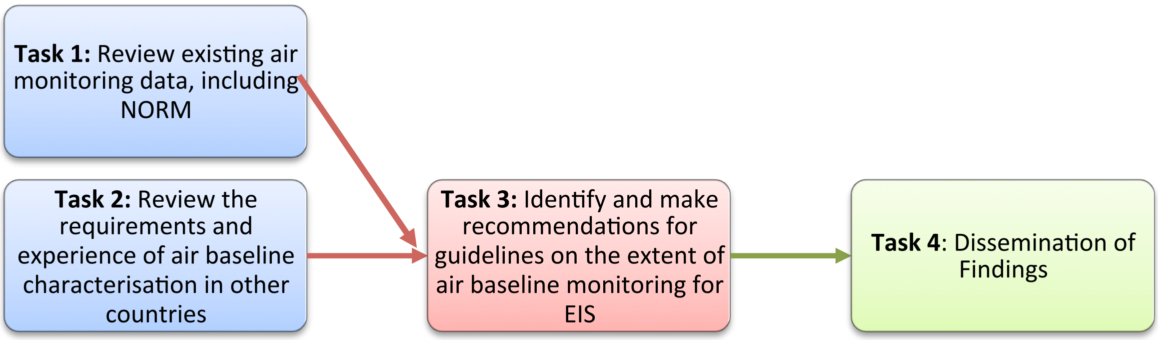

Figure 1.2. Tasks of Project A3 of the UGEE JRP

1.3 Objective and Aim of Final Report A3

Project A3 (Air Quality) deals with the requirements and needs for additional air baseline monitoring (in terms of frequency, locations and the types of pollutants covered) in the context of EISs. This report (*Final Report A3*) specifically describes the work carried out under Tasks 1, 2 and 3 (see Terms of Reference).[5]

This report seeks to address three key objectives:

- Task 1: to review existing air monitoring data, including naturally occurring radioactive materials (NORM);
- Task 2: to review the requirements and experience of air baseline characterisation in countries in which UGEE projects/operations have taken or are taking place;
- Task 3: to identify and make recommendations for guidelines on the extent of the air baseline monitoring (in terms of frequency, locations and the types of pollutants covered) that needs to be carried out for an EIS (i.e. on a project basis).

1.4 Methodology and Information Sources

The preparation of Final Report A3 has involved desk-study work, which was carried out as follows:

5 www.epa.ie/pubs/reports/research/ugeepublicconsultation/ugeeresearchrevisedtermsofreference.html#.VQCVj9KsWik

- The available data and information on existing air quality monitoring programmes in Ireland were obtained and reviewed.
- A literature review of baseline characterisation practices in other countries, notably those in which UGEE has taken place or is planned, with an emphasis on reviewing lessons-learned documentation, was conducted.
- The potential data gaps were identified and guidelines on the extent of the air baseline monitoring (in terms of frequency, location and the types of pollutants covered) that needs to be carried out for an EIS (i.e. on a project basis) were developed.

The sources of data and information include:

- EPA, NIEA and local authority information on the scope of existing air quality monitoring networks;
- reports prepared by national panels and commissions on air quality impacts associated with UGEE activity;
- peer-reviewed technical papers related to UGEE air pollutant emissions;
- peer-reviewed technical papers related to baseline characterisation and impact studies;
- the existing international legislation and guidance on ambient air pollution, and air pollution and emissions associated with UGEE activities;
- publications by national/public bodies on ambient air quality monitoring requirements associated with UGEE activities, and lessons learned.

2 Background

Shale gas is a natural gas found in shale, a fine-grained sedimentary rock. The extraction or production of natural gas from shale differs from conventional forms of gas and oil extraction from defined reservoirs or traps in which the hydrocarbon (i.e. the gas or oil) has migrated from the source rock. In the case of shale gas, the extraction is considered unconventional, as the gas is obtained directly from the source rock itself.

Hydraulic fracturing, or “fracking”, is a method used by drilling engineers to stimulate or improve the flow of oil or gas from rocks in the subsurface.

The initial step is the drilling of a vertical borehole to a prescribed depth, which can be up to thousands of metres below ground. Once the final vertical depth has been reached, the core of the bore hole is encased with cement to prevent contamination of the surrounding rock. Horizontal directional drilling of the rock may take place in different directions, and these horizontal drillings can extend for several thousand metres from the original vertical bore hole.

The technique involves first perforating the well casing with tiny holes using controlled explosive charges. The perforations allow fracturing fluid to enter the formation which, in turn, is followed by the formation’s release of its previously trapped natural gas. The water-rich fracturing fluid is pumped into a borehole at high pressure until the fluid pressure at depth causes the rock to fracture. The pumped fluid contains small particles known as “proppant” (often quartz-rich sand), which serve to prop open the fractures. After the rock has been fractured, the pressure in the well is dropped and the fracturing fluid and expelled natural gas flow back to the wellhead at the surface. The fracking fluid may also contain chemical additives such as acid (to help initiate fractures), corrosion and scale inhibitors (to protect the borehole lining), and gelling agents (to alter fluid viscosity) (Healy, 2012).

The extracted gas is typically methane but may contain small quantities of other gases, including hydrogen sulfide, carbon dioxide, nitrogen, water vapour and other hydrocarbons. The composition of shale gas is dependent on the geological formation, as well as the temperature and pressure that the formation has been subjected to over time.

The European Commission issued a guidance note in 2011 confirming that the exploration and exploitation of unconventional hydrocarbons has to comply with the requirements of EU legislation (EC, 2011b). A comprehensive EU legislative framework on environmental protection and non-discriminatory access to hydrocarbon resources is already in place and applies to all hydrocarbons, conventional and unconventional, from planning to the aftercare of sites following exploitation, including the EIA Directive (2014/52/EU) which entered into force on 15 May 2014.

Across Europe, there is currently considerable interest in developing shale gas resources, with the UK, Poland, Germany, the Netherlands, Spain, Romania, Lithuania, Denmark, Sweden and Hungary all expressing an interest. Until recently, the environmental implications of shale gas exploration and exploitation received little consideration (JRC, 2012). The US Department of Energy has, relatively recently, ordered a comprehensive assessment of challenges, including the environmental challenges, of extended shale gas development (Secretary of Energy Advisory Board, 2011). The US Environmental Protection Agency (USEPA) is also investigating the issue and has promulgated regulations such as Title 40 of the United States Code of Federal Regulations, Part 60, Subpart OOOO, that controls volatile organic compounds (VOCs) and sulfur dioxide (SO_2) emissions from crude oil and natural gas production, transmission and distribution sources. These rules place limitations on well completion operations with hydraulic fracturing, initial flowback and the treatment of recovered gas by a completion combustion device. In Europe, several moratoria are in place pending further development. All of these initiatives are driven by the growing realisation that shale gas development may be restricted by environmental concerns in the future (JRC, 2012). An initial European Commission assessment of hydraulic fracturing practices in the context of shale gas developments has identified a number of potential risks to the environment from these practices, including impacts on air quality (EC, 2012b).

The impacts of shale and other forms of unconventional gas extraction have been the subject of a number of independent reviews in Europe, including reviews by the Tyndall Centre for Climate Change Research (Broderick *et al.*, 2011), a UK House of Commons Committee (House of Commons, 2011a,b) and The Royal Society and The Royal Academy of Engineering (2012), and a European Commission study covering environmental, health and climate change impacts (EP, 2011; AEA, 2012b). All of these reviews have led to the conclusion that there are potential environmental impacts related to air quality associated with shale gas extraction, and have stressed the importance of monitoring these potential impacts.

There have also been several comprehensive reviews and studies performed in the USA and Canada, including comprehensive health impact assessments in the USA (Colorado School of Public Health, 2011; New York State Department of Health, 2014) and a detailed examination of the potential public health impacts in New Brunswick, Canada (OCMOH, New Brunswick Department of Health, 2012), as well as an expert panel review of potential environmental impacts by the Council of Canadian Academies (CCA, 2014).

In addition, a special report by the International Energy Agency (IEA) stresses the need for robust and coherent measures, including “full transparency, measuring and monitoring of environmental impacts” (IEA, 2012), and has recently concluded that “governments, industry and other stakeholders must work together to address legitimate public concerns about the associated environmental and social impacts” of unconventional fossil fuel projects.

Internationally, the determination of potential environmental impacts related to UGEE processes is gaining importance. In nearly all instances in which commercial UGEE operations are proceeding, shale gas extraction has proceeded without the collection of sufficient environmental baseline data. This lack of baseline monitoring has made it difficult to distinguish between ambient air pollution and incremental air pollution from shale gas activities. This impedes the identification of the environmental impacts that may be caused by, or inappropriately blamed on, UGEE activities (Council of Canadian Academics, 2014). Unlike many countries, Ireland is in a position to complete full baseline studies and investigations in the absence of ongoing UGEE works.

3 Unconventional Gas Exploration and Extraction and Air Pollution

3.1 Background

Air contaminants can adversely affect human health in a multitude of ways, as shown in Figure 3.1. The industrial processes involved in UGEE can result in the emission of air pollutants which, if present at high enough concentrations, are associated with possible health impacts through direct contact (e.g. with eyes and skin) or through inhalation (e.g. respiratory tract and gastrointestinal tract) (Atherton *et al.*, 2014). This is in addition to site emissions, which can include VOCs; furthermore, the industrial processes associated with hydraulic fracturing would increase the volume of traffic and the use of diesel-fuelled machinery, and, consequently, emissions of unburned hydrocarbons, VOCs, SO_2, particulate matter (PM), carbon monoxide (CO) and oxides of nitrogen (NO_x). Leaky equipment can also result in fugitive gas emissions, leading to the release of methane and other gases such as VOCs.

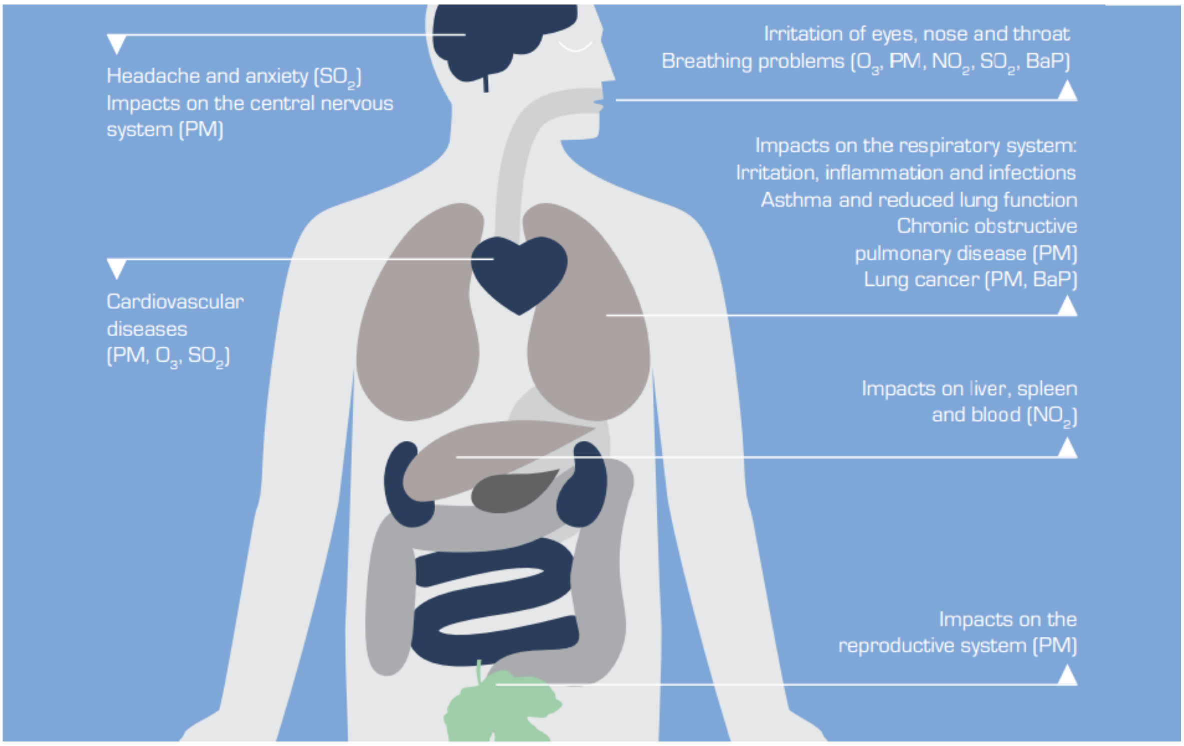

Figure 3.1. Health impacts of air pollution (source: EEA, 2013a).

BaP, benzo[*a*]pyrene.

The emissions from numerous well developments in a local area or across a wider region could have a potentially significant effect on air quality. For example, the emissions of VOCs and NO_x from the wide-scale intensive development of shale gas reservoirs may potentially influence wider ozone (O_3) levels or contribute to elevated ambient pollution levels, which, at high enough concentrations, could potentially contribute to adverse effects on respiratory health.

However, on a site-by-site basis, these emissions are typically intermittent and not unique to shale gas extraction and related activities (Public Health England, 2013). Many pollutants associated with shale gas extraction are also produced in significant quantities from other sources; for example, primary air pollutants result from industry and transport, and secondary pollutants result from atmospheric processes. These sources and processes contribute to background levels of both primary and secondary pollution. Therefore, it is critical that emissions from UGEE processes are put into the context of the existing background levels of ambient air pollution. It is also very important to understand that the background levels of air pollution vary from place to place. In some areas, specific sources, such as traffic, will be dominant, while in other areas, regional, national, or even international sources can be important contributors to the background levels of pollution. Without such data, it is difficult to undertake a detailed assessment of the impact of emissions on human health (Public Health England, 2013).

3.2 Emissions to Ambient Air and the Unconventional Gas Exploitation and Extraction Process

3.2.1 General

UGEE operations and the diesel engines used to support them have the potential to release many hydrocarbons and other contaminants into the air, and may result in increases in the occupational and public exposure of workers in the immediate vicinity and nearby residents to these air contaminants. Potentially, people may be exposed to higher levels of these contaminants than they would otherwise as they breathe ambient air in and outside of their homes. Some of these contaminants, such as benzene, diesel exhaust and PM particles with diameters of 2.5 μm or less ($PM_{2.5}$), are associated with potentially significant negative health impacts at certain levels (Colorado School of Public Health, 2011). Others can act as irritants to the eyes, skin and respiratory tract, or cause neurological effects, if present at high enough concentrations. In addition, hydrocarbons and nitrogen oxides serve as precursors for the formation of ground level O_3, which itself is an irritant.

In terms of life cycle, unconventional natural gas differs from conventional natural gas in three main ways. First, the extraction of unconventional natural gas often requires directional or horizontal drilling at much greater depths below ground surface level. Second, well completion (hydraulic fracturing) procedures for unconventional natural gas are much more extensive and expensive than they are for conventional wells. Third, unconventional natural gas wells are typically associated with a sharper production decline curve and a less well constrained total volume of natural gas recovered per well (based on both economical and practical constraints). Once out of the ground, however, unconventional natural gas is subject to the same fate (e.g. processing, transport, end use) as conventional natural gas, and the atmospheric impacts are indistinguishable between the two forms (Moore *et al*., 2014).

Published evidence from the USA (Groundwater Protection Council, 2009; Colorado School of Public Health, 2011; Walther, 2011; McKenzie *et al.*, 2012; Adgate *et al.*, 2014; Maryland Department of the Environment and Maryland Department of Natural Resources, 2014; Werner *et al.*, 2015) and other countries (Public Health England, 2013) suggests that, potentially, a wide variety of different sources of air pollutants from shale gas extraction and related activities exists and vary depending on the process phase. It should be noted that European restrictions would result in variations in UGEE processes in comparison with the processes used in the USA, from which much of the primary data originate (e.g. holding ponds for flowback fluids would not be permitted in Europe but are permitted in the USA). There would, therefore, be reductions or variations in the overall emission magnitudes associated with restrictions particular to the process stages.

Sources of air pollutants can include:

- direct emissions from the conventional diesel engines that power the drilling and tracking operations, and the compressors that are used to capture and transport the gas on site; pollutants may include PM, CO and NO_x, including nitrogen dioxide (NO_2);
- emissions from the venting of condensate and oil tanks on site; pollutants may include a range of VOCs;
- emissions from gas capture and flaring; pollutants may include methane, NO_x and other gases associated with the flaring of the gas, such as non-methane volatile organic compounds (NMVOCs), as well as PM;

- fugitive emissions associated with leaks from pumps, flanges, valves, pipe connectors, etc.; pollutants may include methane and VOCs;
- emissions of a number of air pollutants associated with shale gas extraction and related activities can lead to the formation of secondary pollutants such as O_3, which is generated by photochemical reactions involving NO_x and VOCs in the presence of sunlight; emissions from shale gas extraction operations may also lead to the formation of secondary particles.

The UGEE process can typically be split into five stages (Branosky *et al.*, 2012):

- pre-production;
- natural gas production;
- natural gas transmission, storage and distribution;
- natural gas end use;
- well production and end-of-life.

In addition to NORM and methane, which are discussed in section 3.3, the main compounds emitted during the various phases of the UGEE process that can impact upon local and regional air quality are shown in Figure 3.2.

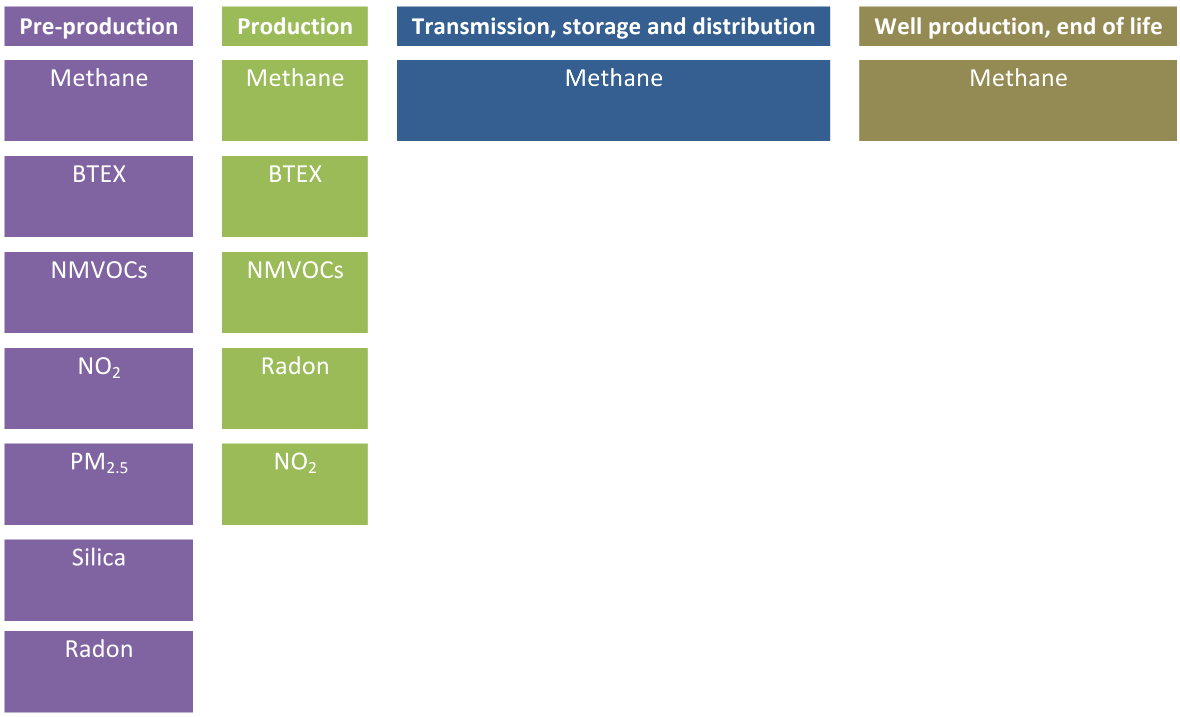

Figure 3.2. Potential species emitted to the atmosphere during specific stages of the natural gas life cycle.

BTEX, benzene, toluene, ethylbenzene and xylene.

3.2.2 Pre-production

The pre-production stage includes everything from exploration, site clearing and earthworks, and road construction to drilling, hydraulic fracturing and well completion. For a single well, pre-production is usually completed within a few weeks, although larger sites can have up to a dozen or more wells on a pad, with the potential for multiple pads in a single area. The pre-production phase for a larger site can, therefore, last several months.

A range of pollutants with impacts on environmental and human health have been linked to this stage (AMEC, 2013). Several studies (NETL, 2013) that are attempting to quantify the individual as well as cumulative impacts are ongoing. However, Moore *et al.* (2014) and Werner *et al.* (2015) report that a complete inventory and a comprehensive classification of emissions during drilling and hydraulic fracturing do not exist.

The use of large diesel-powered equipment during site preparation, including for the construction of roads and holding ponds, as well as clearing and grubbing for the well pad, is the first stage of the UGEE process to have an impact on air quality (Cabot Oil and Gas Corporation, 2013). Emissions are released from off-road diesel engine use and heavy equipment operation, and continue throughout the drilling and hydraulic fracturing phases.

Diesel engine emissions are known to include fine airborne PM (with particles of diameters of 10 µm or less (PM_{10}) and $PM_{2.5}$), as well as O_3 precursors such as NO_x and NMVOCs. These pollutants, in sufficient concentrations, are associated with decreased lung function, asthma and respiratory symptoms, such as coughing and breathing difficulties (CE Delft, 2009; EEA, 2013b; Litovitz *et al.*, 2013). Between 8000 and 1,000,000 m^3 of water (Vengosh *et al.*, 2014), up to 2000 tonnes of sand (Vaughan, 2011), or similar quantities of man-made silica beads and hydraulic fracturing chemicals are transported to and from the well pads for the fracturing fluid and proppant.

Air emissions related to the hydraulic fracturing fluid include PM from raw material transport and handling, and the sand or silica beads used to prepare the proppant. An area of growing concern relates to a particular component of this PM (both PM_{10} and $PM_{2.5}$) on which little information exists: respirable silica (i.e. crystalline silica small enough to enter the gas-exchange regions of the lungs) (Chalupka, 2012; Coussens and Martinez, 2013; Esswein *et al.*, 2013; Korfmacher *et al.*, 2013; Witter *et al.*, 2014; Werner *et al.*, 2015). Crystalline silica dust within the respirable size range (< 4 µm) is classified as a carcinogen and a hazardous air pollutant in the USA (Clark *et al.*, 2013). Silica dust can be generated during the mining and transportation of sand to the well site, as well as in the process of moving and mixing sand into the hydraulic fracturing fluid on the well pad. In addition to an increased risk of lung cancer, exposure to crystalline silica can lead to a chronic, inflammatory lung disease called silicosis (Clark *et al.*, 2013; NIOSH, 2014; Hoffman *et al.*, 2014).

As the well is drilled, pockets of methane and, potentially, ethane and propane can be released. However, little information is available on the frequency and volume of emissions associated with these releases; this is currently a major uncertainty in emission inventories (Jiang *et al.*, 2011; Moore *et al.*; 2014; NOAA, 2015).

The emissions released during drilling and hydraulic fracturing include exhaust from diesel and natural-gas powered engines for drilling rigs and pumps (AMEC, 2013).

The fluid used during hydraulic fracturing can contain hundreds of chemicals, including acids, ethylene glycol and isopropanol (Groundwater Protection Council, 2009). The detailed constituents of the hydraulic fracturing fluid mix are often proprietary, meaning that the reporting of constituents by the industry is voluntary and often incomplete in the USA (InsideClimate News, 2012). However, in the UK, under the new “Infrastructure Bill [HL] 2014–15” under consideration in the House of Lords, a well-by-well disclosure of chemicals in the fracking fluid is required (as of 5 February 2015). When a proportion of the fracturing fluid is returned to the surface, it can be stored in holding ponds or flowback tanks; this is associated with the potential for the emission of fluid components, which can be volatile under atmospheric conditions (Arnaud, 2015; Werner, 2015).

After the completion of the drilling and fracturing processes, the well is complete and prepared to produce natural gas. The emissions released during the well completion process, particularly during the venting and flaring of initial natural gas before the well is connected to a transmission pipeline, can include methane, and benzene, toluene, ethylbenzene and xylene (BTEX) (Adgate *et al.*, 2014; OAQPS, 2014). These emissions can also contain other non-methane hydrocarbons, along with hydrogen sulfide (H_2S) (Skrtic, 2006), NO_x and, if there is incomplete combustion of natural gas, formaldehyde at concentrations in the air that may have the potential to affect residents living within 800 m of a well (McKenzie *et al.*, 2012).

More recently, reduced emissions completions (RECs), or "green completions," which capture and separate natural gas during well completion and workover activities, have become a key technology for limiting the amounts of methane, VOCs and hazardous air pollutants that can be vented during the flowback period without the disadvantages of flaring. RECs use portable equipment that allows operators to capture natural gas from the flowback water. After the mixture passes through a sand trap, a three-phase separator removes natural gas liquids and water from the gas (Clark *et al.*, 2013). For example, green completions and flaring can reduce methane emissions by as much as 95% versus venting straight into the atmosphere. Green completion technology is expected to be further developed and become even more effective as the industry develops (DECC, 2014a).

3.2.3 Production

During production, emission sources can include well-head compressors or pumps that bring the produced gas up to the surface or up to pipeline pressure (engines are often fired with raw or processed natural gas); the bleeding or leaking of well pad equipment; flare emissions; maintenance emissions; and compressor station emissions (Litovitz *et al.*, 2013).

During the production phase, other sources of methane and NMVOCs (including BTEX) can include dehydrator regeneration vents; venting from pneumatic pumps and devices that are actuated by natural gas; leaks as a result of faulty casings; incomplete emissions capture; and incomplete burning in flaring systems. Some of these emissions can be continuous or intermittent, but will occur throughout the lifetime of the well unless direct emissions capture and destruction or recovery are put into place (Moore *et al.*, 2014). Other emissions related to, for example, maintenance or production stimulation will be episodic, such as during liquid unloadings and workovers (Tyner *et al.*, 2014). In addition, oil and gas emissions of O_3 precursors have been linked to elevated regional O_3 levels (Bar-Ilan *et al.*, 2009; Kemball-Cook *et al.*, 2010; Litovitz *et al.*, 2013). High surface-level O_3 concentrations, produced by increased NO_x and VOC abundance, can lead to respiratory symptoms, particularly in children and older adults (WHO, 2003; Ebi and McGregor, 2008).

There is little consensus on the magnitude of the impact on air quality because of a number of factors, including variations in the composition of the raw gas itself, and varying degrees of emission controls and reduction requirements. The conclusions reported by published studies vary from production emissions being significantly detrimental to air quality (Katzenstein *et al.*, 2003; Gilman *et al.*, 2013; USEPA, 2015; Werner *et al.*, 2015) to having little or no impact on air quality (Zielinska *et al.*, 2011; Pacsi *et al.*, 2013; Pennsylvania Department of Environmental Protection, 2013; Bunch *et al.*, 2014).

3.2.4 Transmission, storage, distribution, well production and end-of-life

Much less information exists on the non-methane emissions from the other natural gas life cycle stages. Since pipeline-quality natural gas is predominantly methane (McKenzie *et al.*, 2012), Moore *et al.* (2014) report that few other emissions are reported to be released from the transmission, storage and distribution stage (as illustrated in Figure 3.2).

Once a well no longer produces at an economic rate, the wellhead is removed, the wellbore is filled with cement to prevent leakage of gas into the air ("plugging"), the surface is reclaimed (either to its pre-well state or to another condition agreed upon with the landowner) and the site is abandoned to the holder of the land's surface rights (Clark *et al.*, 2013).

The information that is available on the potential for gas leakage is derived primarily from historical studies of conventional wells. In Alberta, Canada, for instance, 4% of abandoned wellbores leaked, including many that were plugged before abandonment (Watson and Bachu, 2009). Because of the lack of information, it is currently not possible to accurately estimate the air quality impacts of this part of the process life cycle (Watson and Bachu, 2009).

3.2.5 End use

As any emissions related to the end use of the gas product will be released off site, this area is not pertinent to establishing baseline monitoring requirements for UGEE project locations.

3.3 Other Pollutants

3.3.1 Naturally occurring radioactive materials

Potentially, NORM includes all radioactive elements found in the environment. However, the term is used more specifically for all NORM for which human activities have increased the potential for exposure compared with the unaltered situation (World Nuclear Association, 2014). Exposure to naturally occurring radiation is responsible for the majority of an average person's yearly radiation dose and is therefore not usually considered of any special health or safety significance. The Radiological Protection Institute of Ireland (RPII) undertook a comprehensive review of the relevant data on radiation exposure and concluded that the estimated average dose in Ireland from all sources of radiation is 4037 µSv (55% of which is due to indoor radon) (RPII, 2014).

Hydraulic fracturing can release NORM in certain geological environments, both in drill cuttings and water (World Nuclear Association, 2014). The level of NORM accumulation can vary substantially from one facility to another depending on geological formation, operational and other factors (OGP, 2008). In some cases, they are no higher than those in the general environment, and in other cases, elevated levels may mean that protective actions would be necessary (Public Health England, 2013). During the production process, NORM flows with the oil, gas and water mixture, and accumulate in scale, sludge and scrapings. NORM can also form a thin film on the interior surfaces of gas processing equipment and vessels (International Association of Oil & Gas Producers, 2008). NORM is present in the residues (cutting fluids and mud) produced by the initial drilling, although the levels are usually similar to those in the ground beneath, and are not of specific concern. Flowback water can also contain elevated levels of NORM (because of the solubility of the isotopes of radium), and, as a result, site waste management arrangements need to specifically address the appropriate management of flowback water (Public Health England, 2013). The issue of NORM in residues and flowback water is addressed as part of Project B of the UGEE JRC (see *Final Report 4* of the UGEE JRP). To characterise NORM levels, NORM surveys, sampling and analyses need to be conducted (OGP, 2008).

There are two ways in which personnel can be exposed to NORM, namely:

- through irradiation – the external exposure to a source that remains outside the body;
- through contamination – the internal exposure to radioactive material that is taken into the body via inhalation, ingestion or absorption (International Association of Oil & Gas Producers, 2008.)

The health effects associated with exposure to ionising irradiation vary depending on the total amount of energy absorbed, the length of exposure time, the dose rate and the particular organ exposed. A key consideration related to NORM is that exposures are generally quite low and will not result in the acute and severe effects associated with exposure to high radiation levels from man-made sources. However, monitoring is required to ascertain the presence and levels of NORM in a medium (International Association of Oil & Gas Producers, 2008).

The elements of a NORM management strategy are likely to include NORM monitoring (direct and laboratory sampling of materials); the control of contaminated waste and equipment; worker protection and training; the development and implementation of management guidelines; and compliance monitoring. The specifics of the operational management of NORM exposure for any UGEE activities will depend on monitored NORM levels in the residues and flowback water. However, these aspects relate primarily to the operational phase and, as such, are outside the scope of this report, which deals with air pollution in the context of baseline characterisation for environmental impact assessment.

This report focuses primarily on radon because of its gaseous nature (uranium, radium and radon occur naturally in the environment; radon exists as a gas, while uranium and radium exist as solids in rock) and the associated potential impacts on air quality. In addition, the primary radionuclide of concern in natural gas is radon (specifically radon-222) (Pennsylvania Department of Environmental Protection, 2015), and radon is the greatest source of radiation exposure for the public in Ireland (NRCS Interagency Group, 2014).

The radioactive half-life is the time it takes for the radioactivity of a substance to decrease by one-half. The half-life of radon is approximately 4 days (the half-lives of the most common isotopes for radium and uranium, radium-226 and uranium-238, are approximately 1600 years and 4.5 billion years, respectively (New Hampshire Department of Environmental Services, 2007)).

Certain types of rocks and soils, such as granite and volcanic soils, as well as aluminous shales, are more likely to contain radon (WHO, 2002). Radon gas can be found in the soil because of decay from the parent element uranium. Radon can also migrate from soil into groundwater, which can be another route of exposure if the groundwater is used as a water supply source.

The background level of radon naturally present in outdoor air in Ireland is approximately 6 Bq/m^3 (RPII, 2002; Gunning *et al*., 2014). Openings between soil and buildings, such as foundation cracks and the locations at which pipes enter, provide conduits for radon to move into structures. The difference in air pressure, caused by heated indoor air moving up and out of buildings, results in a flow of soil gas towards the indoors, potentially allowing radon to accumulate in structures. This can have impacts on health, such as an increase in the risk of lung cancer (WHO, 2002). Typically, 95% of the exposure of the national population to radon is from indoor air; about 1% of exposure is from drinking water sources (WHO, 2002).

As reported by Burkhart *et al.* (2013), there is some evidence that radon-222, radium-226 and other substances have been detected at the wellheads of fracking operations (McMahon, 2013; Tait *et al.*, 2013). Radon-222 can be released to the air surrounding the well site at two stages:

- Radon-222 can be released once the well is complete and is in the production stage; this is assumed to be due to leakage of the radon-222 from the associated piping and separation tanks/storage tanks at the well site.
- Radon-222 can be released during the flowback period when the fracking water returns to the surface and the radon within the water outgasses once the water is at atmospheric pressure (Burkhart *et al.*, 2013).

A recent peer-reviewed study was carried out in Pennsylvania. This study encompassed radiological surveys at well sites, wastewater treatment plants and landfills, and of gas distribution and end use, and brine-treated roads. Data from five phases of well development and completion were collected: vertical drilling, horizontal drilling, hydraulic fracturing, flowback and production. The media sampled included solids, liquids, natural gas, ambient air and surface radioactivity. The study concluded that there is little or limited potential for radiation exposure to workers and the public from the development, completion, production, transmission, processing, storage and end use of natural gas (Pennsylvania Department of Environmental Protection, 2015).

A total of 17 ambient air samples, for evaluation of radon concentrations, were collected during flowback at four different well sites, approximately 1 m above ground and within 2–14 m of the wellhead. The radon concentrations in these samples were within the range of typical ambient background levels (Pennsylvania Department of Environmental Protection, 2015).

If produced with the oil and gas, radon will usually follow the gas stream. If the natural gas is fractionated, a disproportionately high percentage of radon can concentrate in the propane streams and, to a lesser degree, in the ethane streams (International Association of Oil & Gas Producers, 2008).

Although there are few empirical data available, the available literature indicates that there is little potential for additional radon exposure to the public as a result of the use of natural gas, because of radon's short half-life, the overall concentrations of radon in the supplied gas and its subsequent diffusion and dilution (Anspaugh, 2012; RSI, 2012; Brown, 2014; Pennsylvania Department of Environmental Protection, 2015).

3.3.2 Methane

Methane is the primary chemical constituent of natural gas (70−90% by volume for raw natural gas from the well and > 90% by volume for pipeline-quality natural gas (USEPA, 2013)). Methane can alter global atmospheric chemistry and is a powerful greenhouse gas (USEPA, 2013).

The Fifth Assessment of the Intergovernmental Panel on Climate Change (IPCC) estimates that methane has a global warming potential 28- to 34-fold greater than that of carbon dioxide over a 100-year time frame, and 84- to 86-fold greater over a 20-year time frame. The concentration of surface-level methane in the global atmosphere is about 1.8 ppm, making it the second largest contributor (after carbon dioxide) to the total direct radiative forcing due to long-lived greenhouse gases (O'Hare *et al.*, 2014).

Therefore, with respect to methane, the focus internationally is on life cycle emissions, and the overall contributions to emission inventories, as opposed to ambient concentrations on a project-by-project basis. Ambient concentrations of methane are not set within the framework of the Ambient Air Quality and Cleaner Air for Europe (CAFE) Directive; however, in 2013, the European Commission proposed a revision of the National Emission Ceilings (NEC) Directive (AirClim *et al.*, 2014). The NEC Directive is one of the main pillars of the EU's air pollution legislation and is the main instrument for controlling transboundary air pollutants. For the first time, the proposal includes limits for methane.

The reporting of methane emissions is also currently required under the European Commission's greenhouse gas monitoring mechanism, as well as annual submissions to the United Nations Framework Convention on Climate Change and within the Kyoto Protocol as one of the "basket of six". In addition, Directive 92/91/EEC, which concerns minimum requirements for improving the health and safety of workers in the mineral-extracting industries, sets requirements to protect workers from harmful and/or explosive substances. However, this primarily applies to methane present in such concentrations that it could represent a risk to workers associated with flammability.

Most methane emissions occur during well completion, when the "frack fluid" flows back to the surface. Recent research based on field measurements of ambient air near natural gas well fields in Colorado and Utah, USA, suggest that more than 4% of wells may leak into the atmosphere at some production-stage operations (Bradbury *et al.*, 2013). To meet their obligations, operators can control these emissions by using "green completions", equipment that collects and separates the initial flow of water, sand and gas, and separates them so the gas can be handled (DECC, 2014a).

After well completion, methane emissions during production and processing can come from compressors, pumps, dehydration equipment, chemical processing and incidental leaks (e.g. from pipe joints), particularly in poorly run, leaky operations. These can be reduced by the maintenance of machinery and by using vapour recovery units to limit venting from storage tanks.

In practice, most of the existing studies have drawn upon a narrow set of primary data from shale gas operations in the USA. There is little European evidence, as significant shale gas operations are, with the exception of limited exploration activities, not yet operational in Europe and typical practices are yet to be established (AEA, 2012a). There are, in practice, a small number of life cycle studies that are regularly referenced by the wider literature (AEA, 2012a). These include the studies by Broderick *et al.* (2011); Howarth *et al.* (2011); Jiang *et al.* (2011); Santoro *et al.* (2011); and Stephenson *et al.* (2011). Other studies have been prepared by government agencies, such as the report by Skone *et al.* (2011), which was prepared by the US Department of Energy, National Energy Technology Laboratory (NETL).

Therefore, the key impact with respect to methane relates to life cycle impacts on climate change, as opposed to impacts on health and the environment related to ambient air quality. Baseline measurements of methane are carried out at Mace Head, Ireland, for the World Meteorological Organization (World Meteorological Organization, 2013); however, the consideration of methane in an EIA should focus on life cycle emissions, as opposed to local impacts on ambient air concentrations. Furthermore, while this report proposes that methane measurements are taken as part of the characterisation process, the monitoring of life cycle emissions and the establishment of their levels are likely to be of greater importance.

4 Air Quality Legislation and Guidelines

4.1 Overview

4.1.1 European air quality standards

Although the emission of a range of air pollutants has significantly declined in recent decades in Europe, which has greatly reduced exposure to substances such as SO_2, CO, benzene (C_6H_6) and lead (Pb), air quality continues to be a very important issue for public health, the economy and the environment. Despite the considerable improvements in recent decades, Europe is still far from achieving levels of air quality that do not pose unacceptable risks to humans and the environment (EEA, 2014). However, overall, air quality across the island of Ireland is better than that of other EU Member States (EPA, 2014).

The Europe-wide levels of PM, O_3, reactive nitrogen substances and some organic compounds still pose a significant threat. This is associated with ill health, premature deaths, and damage to ecosystems, crops and buildings. These consequences of air pollutants result in significant losses for the European economy, the productivity of its workforce, and the health of its natural systems (EC, 2011a). The effects of poor air quality have been felt most strongly in two areas:

- in urban areas, in which the majority of the European population lives, which leads to adverse effects on public health;
- in ecosystems, for which the pressures of air pollution impair vegetation growth and harm biodiversity.

The key elements of EU air quality legislation are:

- Air quality legislation defines EU limit values, which are legally binding concentration thresholds that must not be exceeded. Limit values are set for individual pollutants and are made up of a concentration limit, an average time over which a pollutant must be measured or estimated, the number of exceedances allowed per year (if any), and a date by which the limit value must be achieved. Some pollutants have more than one limit value covering different endpoints or average times. Limit values are legally binding in EU Member States.
- Air quality legislation defines target values, which should be attained if possible by taking all necessary measures without entailing disproportionate costs. Target values are not legally binding.
- Air quality legislation stipulates exposure reduction obligations, which stipulate the concentrations by which exposure must be reduced, between 2008–2010 and 2018–2020, by a given per cent, depending on the mean triennial urban background concentrations of $PM_{2.5}$.

Air quality limits and target values in Ireland are defined in EU legislation, the CAFE Directive (EP and CEU, 2008) and the Fourth Daughter Directive (EP and CEU, 2005). The CAFE Directive is an amalgamation of the Air Quality Framework Directive and the subsequent First, Second and Third Daughter Directives. The EU intends to incorporate the Fourth Daughter Directive into the CAFE Directive in the future.

The CAFE Directive did not introduce any changes to the existing limit values for SO_2, NO_2, NO_X, CO, O_3, benzene or lead; however, the upper and lower assessment thresholds for PM_{10} were increased. The Stage II limit value for PM_{10} set out in the First Daughter Directive (99/30/EC) is not included in the CAFE Directive and no longer applies. The CAFE Directive introduced a limit value for $PM_{2.5}$. It also stipulates that each Member State should provide an average exposure indicator (AEI) value for $PM_{2.5}$, which should be an annual concentration, averaged over 3 years. Based on this value, a mandatory percentage reduction, to be achieved by 2020, will be assigned to each Member State. For the island of Ireland, this reduction target is known as the $PM_{2.5}$ national exposure reduction target ($PM_{2.5}$ NERT). In addition, Member States will be required to undertake $PM_{2.5}$ speciation studies to determine the sources of background $PM_{2.5}$ levels.

The CAFE Directive was transposed into Irish legislation by the Air Quality Standards Regulations 2011 (Statutory Instrument (S.I.) No. 180/2011). It replaces the Air Quality Standards Regulations 2002 (S.I. No. 271/2002), the Ozone in Ambient Air Regulations 2004 (S.I. No. 53/2004) and S.I. No. 33/1999. The Fourth Daughter Directive was transposed by the Arsenic, Cadmium, Mercury, Nickel and Polycyclic Aromatic Hydrocarbons in Ambient Air Regulations 2009 (S.I. No. 58/2009).

The Air Quality Standards Regulations (Northern Ireland) 2010 transpose the provisions of the above Directives into Northern Ireland's legislation. As well as the EU limit values and non-mandatory target values for ambient concentrations of pollutants, the Air Quality Standards Regulations (Northern Ireland) 2010 set out requirements for ambient air quality monitoring and identify the duties of the departments of the Northern Ireland Government in relation to achieving limit and target values.

In addition, the Air Quality Strategy for England, Scotland, Wales and Northern Ireland, first published in 1997 and updated in 2007, provides a comprehensive framework for tackling air pollution. It was established on the basis of strong scientific evidence and a science-based understanding of the effects of air pollutants on health and the environment (DEFRA *et al.*, 2007).

Since 2012, the European Commission has been carrying out a review on air quality policy and legislation. This review is ongoing. The Seventh Environmental Action Plan has outlined the pressing need to update the various air quality directives, and set out clear goals for the EU, by 2020.

The limit values and objectives, as set out in the aforementioned directives, can be used as the assessment criteria for the determination of potential air quality impacts.

The periods over which average concentrations are calculated relate to the nature of the potential impacts. Some pollutants have limits that are expressed as annual averages as a result of the chronic nature of the impacts on human health or the environment, that is, the effects occur after a prolonged period of exposure to elevated concentrations. Other compounds have limits that are expressed as short-term averages (e.g. 15-minute, 1-hour or 24-hour averages); this is as a result of the acute way in which they can affect health or the environment. Some compounds have both short- and long-term average limits, to prevent both chronic and acute impacts.

4.1.2 World Health Organization Standards

While air quality standards are set by each country to protect the public health of their citizens and, as such, are an important component of national risk management and environmental policies, World Health Organization (WHO) guidelines are designed to offer guidance on reducing the health-related impacts of air pollution. The WHO air quality guidelines (WHO, 2006) are based on the now extensive body of scientific evidence related to air pollution and its health consequences, and can often be more stringent than national air quality standards.

4.2 Nitrogen Oxides

NO_X refers to both nitric oxide (NO) and NO_2. They are produced during combustion at high temperatures. The main sources of NO_X emissions in island of Ireland are vehicles and power stations. The industrial sector is also a significant contributor to NO_x levels in the island of Ireland, particularly the cement production industry. The majority of NO_X emissions are in the form of NO, with typically 5–10% being directly emitted NO_2. NO reacts with oxygen or O_3 in the air to form NO_2. Diesel engines tend to emit a higher percentage of NO_2 than petrol.

The current European and WHO limits and threshold values for NO_2 and NO_X are set out in Table 4.1 and Table 4.2, below (EPA, 2014). For NO_2, two limit values and an alert threshold are defined for the protection of human health. The limit values are specified for short-term (1-hour) and long-term (annual) exposure. The 1-hour value can be exceeded up to 18 times per year before the limit value is breached. For the protection of vegetation, a critical level is set for the annual mean of NO_X, defined as the sum of NO and NO_2 expressed in units of mass concentration of NO_2.

The legislation also defines an alert threshold value of 400 μg/m^3. If this value is exceeded over three consecutive hours at locations representative of air quality covering at least 100 km^2 or an entire air quality management zone or agglomeration, local authorities have to implement short-term action plans. These action plans may include measures related to motor vehicle traffic, construction works, ships at berth, or the use of industrial plants or products and residential heating. Specific actions aimed at the protection of sensitive population groups, including children, may also be considered in the framework of these plans (EPA, 2014).

Table 4.1. Limit and threshold values for NO_2 and NO_X as set out in the 2008 CAFE Directive and S.I. No. 180/2011

Objective	Averaging period	Limit or threshold value	Number of allowed exceedances
Human health	1 hour	200 μg/m^3 NO_2	18 hours per year
Human health	1 calendar year	40 μg/m^3 NO_2	
Alert[a]	1 hour	400 μg/m^3 NO_2	
Protection of ecosystems	1 calendar year	30 μg/m^3 NO_x	
Upper assessment threshold for human health	1 calendar year	32 μg/m^3 NO_2	
Lower assessment threshold for human health	1 calendar year	26 μg/m^3 NO_2	

[a]To be measured over three consecutive hours at locations representative of air quality, covering at least 100 km^2 or an entire zone or agglomeration, whichever is smaller.

Table 4.2. WHO air quality guidelines for NO_2

Pollutant	1-hour mean	Annual mean
NO_2	200 μg/m^3	40 μg/m^3

4.3 Sulfur Dioxide

SO_2 is a gas which is formed when sulfur-containing fuels (mainly coal and oil) are burned in power stations, domestically or elsewhere. In the island of Ireland, fuel switching, from solid and liquid fuels to natural gas, in the power generation and industry sectors has been a significant contributor to the decrease in emissions since 1990. The application of flue gas desulfurisation at the Moneypoint coal-fired power station, in County Clare, Ireland, has also led to a substantial reduction in SO_2 emissions from this key point source. Over the last 10 years, a slight downwards trend in SO_2 levels has reflected the shift from sulfur-containing bituminous coal to fuels, such as natural gas, that produce lower levels of SO_2. Levels of SO_2 are relatively low across much of the EU, because industrial abatement technology has been largely successful in tackling this pollutant (EPA, 2014).

Table 4.3 and Table 4.4 show the EU limits and WHO guidelines for SO_2 levels.

Table 4.3. Limit and threshold values for SO_2 as set out in the 2008 CAFE Directive and S.I. No. 180/2011

Objective	Averaging period	Limit or threshold value	Number of allowed exceedances
Human health	1 hour	350 µg/m^3	24 hours per year
Human health	1 day	125 µg/m^3	3 days per year
Alert[a]	1 hour	500 µg/m^3	
Vegetation	1 calendar year	20 µg/m^3	
Upper assessment threshold for human health	1 day	75 µg/m^3	3 days per year
Lower assessment threshold for human health	1 day	50 µg/m^3	3 days per year

[a]To be measured over three consecutive hours at locations representative of air quality, covering at least 100 km^2 or an entire zone or agglomeration, whichever is smaller.

Table 4.4. WHO air quality guidelines for SO_2

Pollutant	10-minute mean	24-hr mean
SO_2	500 µg/m^3	20 µg/m^3

4.4 Carbon Monoxide

CO is a colourless gas, formed from incomplete oxidation during combustion of fuel. In the island of Ireland, CO is mainly from automobiles, although tobacco smoke and poorly adjusted and maintained combustion devices, such as boilers, also contribute. CO concentrations tend to be higher in areas with heavy traffic congestion than in other areas (EPA, 2014).

Table 4.5 and Table 4.6 show the EU limits and WHO guidelines for CO levels.

Table 4.5. Air quality limit values set by the CAFE Directive and S.I. No. 180/2011 for CO

Objective	Hourly	8-hour average
Human Health	–	10 mg/m^3
Annual limit value upper assessment threshold	–	7 mg/m^3
Annual limit value lower assessment threshold	–	5 mg/m^3

Table 4.6. WHO air quality guideline values for CO

Pollutant	Hourly	8-hour average
CO	30 mg/m^3	10 mg/m^3

4.5 Ozone

O_3 is a gas that is formed as a secondary pollutant at ground level by the reaction of a mixture of other chemicals (O_3 precursors, NO_X, CO and VOCs) in the presence of sunlight. Ground-level O_3 is depleted through reactions with traffic-emitted pollutants; therefore, levels of O_3 tend to be higher in rural areas than in urban areas (EPA, 2014). The reactions that create O_3 are catalysed by heat and sunlight – so O_3

is a particular problem in the summer months, and southern Europe typically has much higher levels of O_3 than northern Europe (EPA, 2014).

Rural background stations are classified as remote, regional or near-city, depending on their proximity to urban areas. O_3 levels are higher in remote regions and tend to be highest along the western seaboard (indicated by the Galway and Kerry sites) and lower in the east of Ireland (indicated by the Monaghan site).

Table 4.7 and Table 4.8 show the EU limits and WHO guidelines for O_3 levels. The AOT_{40} (accumulated O_3 over a threshold of 40 ppb) value, shown in Table 4.7, is an indicator of the exposure of vegetation to O_3 during the growing season, during which vegetation is more susceptible to damage from pollutants (EPA, 2014).

Table 4.7. Air quality limit values for O_3 as set out in the 2008 CAFE Directive and S.I. No. 180 of 2011

Objective	Averaging period	Limit or threshold value	Comments
Human health	Daily maximum 8-hour mean	350 $\mu g/m^3$	25 days per year averaged over 3 years
Vegetation	AOT_{40}[a] accumulated over May–July	125 $\mu g/m^3$	
Long-term objective: health	Daily maximum 8-hour mean	500 $\mu g/m^3$	
Long-term objective: vegetation	AOT_{40} accumulated over May–July	20 $\mu g/m^3$	
Information	1 hour	75 $\mu g/m^3$	
Alert[b]	1 hour	50 $\mu g/m^3$	

[a]The AOT_{40} value is the sum of the difference between hourly concentrations greater than 80 $\mu g/m^3$ (40 ppb) and 80 $\mu g/m^3$ over a given period using only the 1-hour values measured between 08:00 and 20:00 Central European Time each day.

[b]To be measured over three consecutive hours.

Table 4.8. WHO air quality guideline value for O_3

Averaging period	Limit or threshold value
Daily maximum 8-hour mean	100 $\mu g/m^3$

4.6 Particulate Matter (PM_{10})

PM_{10} are particles with diameters of 10 µm or less. These particles can consist of direct emissions, such as dust, emissions from combustion engines, emissions from the burning of solid fuels or natural sources including windblown salt, plant spores and pollens. These direct emissions are known as primary PM_{10}. PM_{10} can also be produced indirectly by the formation of aerosols as a result of the reactions of other pollutants, such as NO_X and SO_2; these are known as secondary PM_{10}. In the island of Ireland, the main sources of PM_{10} are the burning of solid fuels and vehicular traffic.

The PM_{10} limit and target values for health protection are shown in Table 4.9. The deadline for Member States to meet the PM_{10} limit values was 1 January 2005. For PM_{10}, there are limit values for short-term (24-hour) and long-term (annual) exposure. In Europe, the short-term limit value for PM_{10} (i.e. not more than 35 days per year with a daily average concentration exceeding 50 $\mu g/m^3$) is the limit value most often exceeded in European cities and urban areas. Table 4.10 shows the WHO air quality guideline values for PM_{10}.

Table 4.9. Air quality limit and target values for PM_{10} as set out by the CAFE Directive and S.I. No. 180/2011

Objective	Averaging period	Limit or threshold value	Number of allowed exceedances
PM_{10} limit value	1 day	50 μg/m^3	Not to be exceeded on more than 35 days per year
PM_{10} limit value	1 calendar year	40 μg/m^3	
Upper assessment threshold	1 day	35 μg/m^3	Not to be exceeded on more than 35 days per year
Lower assessment threshold	1 day	25 μg/m^3	Not to be exceeded on more than 35 days per year
Upper assessment threshold	1 calendar year	28 μg/m^3	
Lower assessment threshold	1 calendar year	20 μg/m^3	

Table 4.10. WHO air quality guideline values for PM_{10}

Pollutant	24-hr mean	Annual mean
PM_{10}	50 μg/m^3	20 μg/m3

4.7 Particulate Matter ($PM_{2.5}$)

$PM_{2.5}$, also known as "fine" PM, are particles with diameters of 2.5 μm or less (including respirable silica, as mentioned in section 3.2.2). $PM_{2.5}$ can be a mixture of solid and liquid particles composed of varying components depending on the source. These can include acids, such as nitrates and sulfates, VOCs, metals, and soil or dust particles. $PM_{2.5}$ can be emitted directly into the atmosphere or can be formed secondarily. For example, sulfate particles are formed by the chemical reaction of SO_2 in the atmosphere after its release from power plants or industrial facilities. $PM_{2.5}$ is considered a better indicator of man-made PM than PM_{10} (EC Technical Working Group on Particles, 1997)

The deadline for meeting the target value for $PM_{2.5}$ (25 μg/m^3) was 1 January 2010, while the deadlines for meeting the other limit and "obligation" values for $PM_{2.5}$ (20 μg/m^3) were 2015 or 2020. The PM_{10} limit and target values for health protection are shown in Table 4.11. The WHO air quality guidelines for $PM_{2.5}$ are shown in Table 4.12 (EPA, 2014).

Table 4.11. Air quality limit and target values for $PM_{2.5}$ as set out by the CAFE Directive and S.I. No. 180/2011

Objective	Averaging period	Limit or threshold value	Number of allowed exceedances
$PM_{2.5}$ target value	1 calendar year	25 μg/m^3	To be met by 1 January 2010
$PM_{2.5}$ limit value	1 calendar year	25 μg/m^3	To be met by 1 January 2015
$PM_{2.5}$ limit value[a]	1 calendar year	20 μg/m^3	To be met by 1 January 2020
Upper assessment threshold	1 calendar year	17 μg/m^3	
Lower assessment threshold	1 calendar year	12 μg/m^3	

Objective	Averaging period	Limit or threshold value	Number of allowed exceedances
$PM_{2.5}$ exposure concentration obligation[b]		20 µg/m^3	To be met by 1 January 2015
$PM_{2.5}$ exposure reduction target*	0–20% reduction in exposure (depending on the average exposure indicator in the reference year) to be met by 2020	25 µg/m^3	

[a]Indicative limit value (Stage 2) to be reviewed by the European Commission in light of further information on health and environmental effects, technical feasibility and experience of the target value in Member States.

[b]Based on a 3-year average.

Table 4.12. WHO air quality guideline values for $PM_{2.5}$

Pollutant	24-hr mean	Annual mean
$PM_{2.5}$	25 µg/m^3	10 µg/m^3

4.8 Benzene

Urban areas can have measurable quantities of benzene in the air. The major sources of benzene and VOCs in the island of Ireland are automobile exhaust emissions, as regular unleaded petrol may contain up to 1% benzene. Benzene and VOCs can also be released to the air from petroleum refining, fuel storage/filling stations, industrial emissions, chemical usage and tobacco smoke. The relevant Irish and European legislation limit values for benzene are shown in Table 4.13. As benzene is carcinogenic to humans and no safe level of exposure can be recommended, the WHO have not defined a guideline level (Table 4.14) (WHO, 2000).

Table 4.13. Limit value for benzene as set out in the CAFE Directive and S.I. No. 180/2011

Objective	Averaging period	Limit or threshold value	Number of allowed exceedances
Human health	1 hour	200 µg/m^3	18 hours per year
Human health	1 calendar year	40 µg/m^3	
Alert[a]	1 hour	400 µg/m^3	
Vegetation	1 calendar year	30 µg/m^3	
Upper assessment threshold for human health	1 calendar year	32 µg/m^3	
Lower assessment threshold for human health	1 calendar year	26 µg/m^3	

[a]To be measured over three consecutive hours at locations representative of air quality, covering at least 100 km^2 or an entire zone or agglomeration, whichever is smaller.

Table 4.14. WHO air quality guideline for benzene

Objective	Averaging period
Human health	Benzene is carcinogenic to humans and, therefore, no safe level of exposure can be recommended

4.9 Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are chemical compounds which consist of two or more fused aromatic rings made entirely from carbon and hydrogen. PAHs are emitted domestically from the combustion of solid fuels, such as peat, wood and coal, and they can be emitted as a result of the incomplete combustion of fuel in automobiles. Waste burning or “backyard burning” and bonfires are also a source of PAHs, as is cigarette smoke.

PAH deposition from air pollution can also have a significant impact on the quality of water. It is considered that rainfall deposition arising from airborne PAH emissions may be a significant source of PAHs in many surface waters, particularly in rural areas.

PAHs are monitored based on the premise that one particular compound can be used as a marker for all PAHs. This compound is benzo[*a*]pyrene (BaP) and the target value and assessment thresholds for BaP are shown in Table 4.15. The WHO has not set any guidelines for BaP (Table 4.16). The effects on human health will depend mainly on the extent of exposure (length of time, etc.), the amount (or concentration) a person is exposed to and the innate toxicity of the PAHs. A variety of other factors, including pre-existing health status and age, can also affect the impact such exposure has on health. Health-related effects of the chronic or long-term exposure to PAHs may include cataracts, kidney and liver damage, and jaundice. Laboratory studies in mice demonstrate that ingestion of high levels of BaP during pregnancy result in reproductive problems in the exposed mice and their offspring. Birth defects and decreased body weight were also observed in the offspring of exposed mice. It is not known whether or not these effects would occur in humans (SA Health, Government of South Australia, 2009).

Table 4.15. Air quality target value and assessment thresholds for the PAH BaP as set out in the Fourth Daughter Directive and S.I. No. 58/2009

Objective	**Averaging period**	**Limit or threshold value**	**Comments**
Target value	1 calendar year	1 ng/m^3	Target value to be met by 2013
Upper assessment threshold	1 calendar year	0.6 ng/m^3	
Lower assessment threshold	1 calendar year	10.4 ng/m^3	

Table 4.16. WHO air quality reference level for BaP producing excess lifetime cancer risks of 1 in 100,000

Averaging period	**Limit or threshold value**[a]
Annual mean	0.12 ng/m^3

[a]As the WHO has not set an air quality guideline for BaP, the WHO reference level in this table was estimated by assuming an additional lifetime risk of 1 in 100,000, based on epidemiological data from studies in coke-oven workers.

4.10 Naturally Occurring Radioactive Material

Since 1928, the International Commission on Radiological Protection (ICRP) has developed and maintained the International System of Radiological Protection. This is used worldwide as the common basis for radiological protection standards, legislation, guidelines, programmes and practice.

Radon has been a subject of regulatory control in the EU and in other European countries since the ICRP Publication 50 recommendations, related to the lung cancer risk associated with the exposure to radon in dwellings and workplaces, were published in 1987 (ICRP, 1987). The principles were implemented in a subsequent, ICRP Publication 60 (ICRP, 1991), and in the European Commission’s Recommendation “on the protection of the public against indoor exposure to radon” (90/143/Euratom) published in 1990 (EC, 1990).

In May 2000, legal controls were introduced in Ireland that cover work activities for which the presence of natural radioactivity could lead to the risk of a significant increase in the exposure of workers or members of the public. These controls are set out in the Radiological Protection Act, 1991 (Ionising Radiation) Order, 2000 (S.I. 125/2000), which implements European Council Directive 96/29/Euratom (CEU, 1996). In particular, Article 3 of S.I. 125/2000 provides for the regulation of NORM in the workplace if it is likely to give rise to a radiation dose of greater than 1 mSv in a period of 12 months.

In 1993, the ICRP published details for workplaces with regard to setting the limit of 10 mSv/y (above which intervention is almost always justified), defining radon-prone areas and limiting the radon from building materials. Concepts related to workplaces were included in Council Directive 96/29/Euratom (CEU, 1996). The basic principles of protection against radon have recently been updated and consolidated in Basic Safety Standard Directive 2013/59/Euratom (CEU, 2014) based on ICRP Publication 103 (ICPR, 2007).

The impact of the new BSS Directive will be important for many EU Member States, since it implies, for the first time, that there is an obligation to develop a regulatory framework for actively reducing the radon exposure not only of workers, but also of the general public, and lowering the reference level for the annual average activity concentration in air to a maximum value of 300 Bq/m^3.

In addition, the International Association of Oil & Gas Producers has produced *Guidelines for the Management of Naturally Occurring Radioactive Material (NORM) in the Oil & Gas Industry* to set out the components of an effective NORM management process in the oil and gas extraction industry (International Association of Oil & Gas Producers, 2008).

Around 90% of human radiation exposure arises from natural sources such as cosmic radiation, exposure to radon gas and terrestrial radiation. However, some industries that process natural resources may concentrate radionuclides to a degree that may pose risks to both humans and the environment if they are not controlled (Organo *et al.*, 2005).

The exposure pathways to NORM that relate to the oil and gas industry are gamma radiation (via external exposure), radon and radon daughters (internal exposure), and contaminated dust (through inhalation) (Elegba and Funtua, 2005). The substantial depth at which fracking takes place means that it is difficult to envisage how it might cause the physical changes that would be necessary for a significant short- or long-term change in the release of radon from the Earth's surface. Radon may separate from produced water at the wellhead (Brown, 2014), or boreholes for shale gas exploration might pass through rock layers that have naturally elevated radon concentrations. Provided the integrity of the impervious casings of these wellbores is maintained, radon is unlikely to intrude into the wellbore from the surrounding rock (Public Health England, 2013).

5 Review of the Existing Air Monitoring Network

5.1 Introduction

Ambient air quality monitoring networks are designed and used to meet a variety of purposes, such as the monitoring of compliance with air quality standards, the assessment of population exposure to pollutants, the assessment of pollutant transport, air quality index reporting, the monitoring of specific emission sources, the monitoring of background conditions, etc. These purposes may be prioritised as primary or secondary, and individual monitors within a network may serve different purposes (USEPA, 2007).

This section describes the existing ambient monitoring networks within the island of Ireland including the Ambient Air Monitoring Network of Ireland (Ireland AMN) and the Ambient Air Monitoring Network of Northern Ireland (Northern Ireland AMN). Ireland and Northern Ireland have separate environmental regulatory authorities, and the ambient air quality monitoring networks are not directly connected. This chapter describes each network and its regulatory purpose, the air pollutants monitored and some of the salient monitoring requirements.

5.2 Overview of the Ambient Air Monitoring Network in Ireland

The Ireland AMN consists primarily of 32 monitoring stations located throughout the country (see Figure 5.1), and three of these stations were added in 2013. The EPA is the designated competent authority for the implementation of all Irish and EU ambient air quality legislation in the Ireland and is responsible for the monitoring of ambient air quality in order to determine compliance with ambient air quality standards. It is supported in this role by the local authorities.

The Ireland AMN exists primarily to:

- monitor compliance with ambient air quality legislation;
- allow the calculation of air quality indexes on a regional basis.

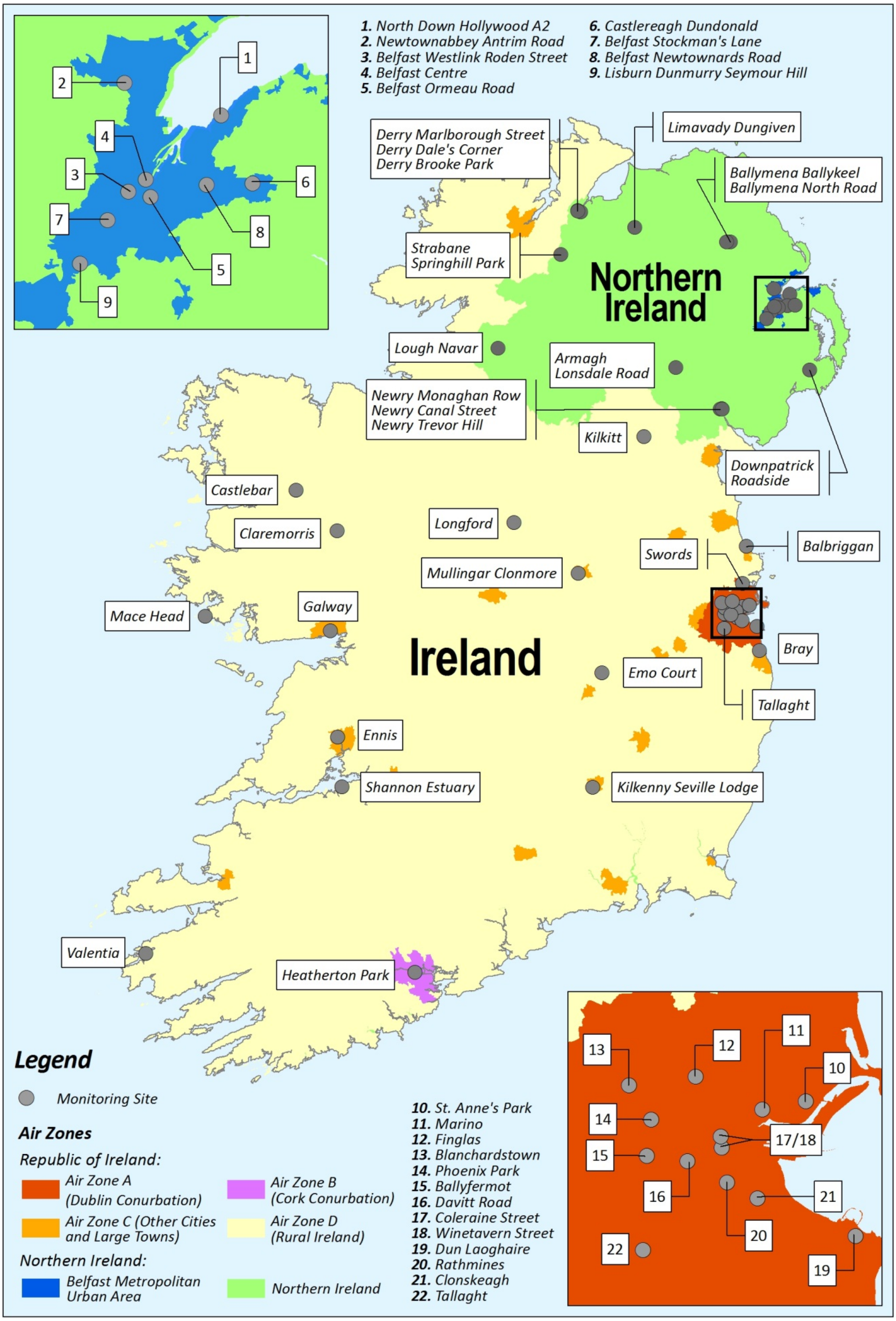

Figure 5.1. Ambient Air Quality Monitoring Networks in Ireland and Northern Ireland.

5.2.1 Ambient air quality monitoring zones in Ireland

EU legislation on air quality (the CAFE Directive) requires that Member States divide their territory into zones for the assessment and management of air quality (EP and CEU, 2008). These zones are shown in Figure 5.2. In Ireland, Zone A is the Dublin conurbation, Zone B is the Cork conurbation and Zone C comprises 23 large towns in Ireland with populations of more than 15,000. Zone D is the remaining area of Ireland. The zones were revised on 1 January 2013 to reflect the results of the 2011 census.

5.2.2 Monitoring frequency, assessment threshold and pollutants

The number of monitoring locations required is dependent on population size and whether ambient air quality concentrations exceed the upper assessment threshold, are between the upper and lower assessment thresholds, or are below the lower assessment threshold.

The greatest possible monitoring effort should apply if concentrations are above the upper assessment threshold, that is, if they approach or exceed the limit value. If concentrations are between the two thresholds, less intensive measurements combined with other assessment methods, such as air quality modelling, will suffice. Only sites that meet the stringent siting criteria of the CAFE Directive may be used for reporting to the European Commission.

Various stations in the monitoring network measure levels of:

- SO_2;
- NO_2 and NO_x;
- CO;
- O_3;
- PM (PM_{10} and $PM_{2.5}$);
- benzene and VOCs;
- heavy metals (lead, arsenic, cadmium, nickel and mercury);
- PAHs;
- elemental carbon/organic carbon, as part of $PM_{2.5}$ speciation;
- anions and cations, as part of $PM_{2.5}$ speciation.

Details of the range of compounds monitored at the various monitoring stations are shown in Table 5.1.

The ambient air quality in Zone D is likely to be most representative of potential UGEE areas.

5.2.3 Naturally occurring radioactive materials: radioactivity monitoring in Ireland

One of the functions of the RPII was to monitor levels of radioactivity in the Irish environment (RPII, 2012). The RPII merged with the EPA in 2014 as part of the Irish Government's Public Sector Reform Plan. The EPA continues to carry out testing to ensure that environmental radiation remains within internationally agreed and legal safety limits. The EPA operates a network of 15 permanent radiation monitoring stations across Ireland to constantly monitor radiation levels in the environment (see Figure 5.11).

The key elements of the radiation monitoring programme are as follows:

- Ambient radioactivity is assessed based on measurements of radioactivity in air and the external gamma dose rate (gamma radiation is emitted from natural and man-made radioactivity present in the environment), obtained from a network of permanent monitoring stations located throughout the country. This permanent monitoring network would also provide the first indication of abnormal levels of radioactivity resulting from a nuclear emergency.

- The assessment of levels of radioactivity in a variety of food products and drinking water.
- The assessment of levels of radioactivity in the Irish marine environment based on seawater, sediment, seaweed, fish and shellfish.

On average, a person in Ireland receives an annual dose of 4037 µSv from all sources of radiation, 55% of which is from indoor radon. By far the largest contribution, of approximately 86% (3400 µSv), comes from natural sources, mainly from the accumulation of radon gas in homes (RPII, 2014). Further information is available on the EPA website (www.epa.ie), including a 10-km grid radon map (available online: gis.epa.ie).

5.3 Overview of the Ambient Air Monitoring Network in Northern Ireland

In the UK, air quality management is a devolved matter, and the Northern Ireland administration is responsible for the jurisdiction's air quality policy and legislation, and the UK government leads on international and European legislation.

In order to improve air quality for all citizens in Northern Ireland, local authorities are responsible for reviewing the state of the air quality in their district. To assist them with this process, an Air Quality Strategy has been devised for the UK (DEFRA *et al.*, 2007). This sets down standards and objectives with regard to the air pollutants that cause problems, and allows local authorities to review the air quality in their area.

A wide range of air quality monitoring is carried out in Northern Ireland. Some monitoring sites are run as part of UK-wide monitoring networks; others are operated by district councils in order to meet local objectives. The monitoring stations are shown in Figure 5.1.

5.3.1 Ambient air quality monitoring zones in Northern Ireland

Northern Ireland comprises two reporting zones – the "Belfast Metropolitan Urban Area" agglomeration (the conurbation of Belfast) and "Northern Ireland" (the rest of the country) (DOENI, 2014), as shown in Figure 5.2.

The number of monitoring sites needed in each zone is based on size and population, in accordance with the CAFE Directive. The CAFE Directive siting criteria are different from those used for local air quality management (LAQM); for example, sites close to major road junctions are used for LAQM, but must not be used for CAFE Directive compliance monitoring purposes. There are also different criteria regarding relevant public exposure.

Table 5.1. The compounds measured across the monitoring networks in Ireland and Northern Ireland

	Zone	Stations	$PM_{2.5}$	PM_{10}	NO_2	NO	SO_2	O_3	CO	Benzene	BaP
Ireland	Zone A	Winetavern St	✓	✓	✓	✓		✓			
		Balbriggan	✓	✓	✓	✓		✓		✓	
		Coleraine St.	✓	✓	✓	✓			✓		
		Rathmines	✓	✓	✓		✓	✓	✓	✓	
		Clonskeagh					✓				
		Dun Laoghaire	✓	✓				✓			
		Ballyfermot	✓	✓				✓			
		Blanchardstown	✓	✓				✓			
		St Anne's Park	✓	✓							
		Swords	✓	✓			✓				

	Zone	Stations	$PM_{2.5}$	PM_{10}	NO_2	NO	SO_2	O_3	CO	Benzene	BaP
		Tallaght			✓			✓			
		Phoenix Park						✓			
		Davitt Road						✓			
		Finglas						✓			
		St Anne's Park						✓			
		Marino							✓		
	Zone B	Old Station Road	✓	✓	✓	✓	✓	✓	✓	✓	
		Hetherton Park						✓			✓
	Zone C	Kilkenny Seville Lodge	✓	✓							
		Kilkenny					✓				
		Ennis			✓			✓	✓		
		Mullingar	✓	✓	✓	✓		✓		✓	
		Bray					✓	✓			
		Galway						✓			✓
	Zone D	Emo, Laois	✓	✓			✓				
		Castlebar, Mayo	✓	✓			✓	✓			
		Kilkitt, Monaghan	✓	✓			✓	✓			✓
		Shannon Estuary			✓						
		Mace Head					✓				
		Valentia					✓				
		Claremorris						✓	✓		
		Longford							✓		
Northern Ireland	Belfast Metropolitan Urban Area	Armagh Lonsdale Road		✓	✓	✓					
		Ballymena Ballykeel		✓			✓				✓
		Ballymena North Road			✓	✓					
		Belfast Centre	✓	✓	✓	✓	✓	✓	✓	✓	
		Belfast Newtownards Road			✓	✓					
		Belfast Ormeau Road			✓	✓					
		Belfast Stockman's Lane		✓	✓	✓					
		Belfast Westlink Roden Street		✓	✓	✓					
	Northern Ireland	Castlereagh Dundonald			✓	✓					
		Derry Brandywell									✓
		Derry Brooke Park	✓	✓	✓	✓	✓	✓	✓		
		Derry Dale's Corner			✓	✓					
		Derry Marlborough Street			✓	✓					
		Downpatrick Roadside			✓	✓					
		Kilmakee Leisure Centre, Dunmurry									✓
		Limavady Dungiven			✓	✓					
		Lisburn Dunmurry Seymour Hill	✓	✓			✓				
		Lough Navar		✓				✓			
		Newry Canal Street		✓	✓	✓					
		Newry Monaghan Row		✓							
		Newry Trevor Hill		✓	✓	✓					
		Newtownabbey Antrim Road			✓	✓					
		North Down Holywood A2		✓	✓	✓					
		Strabane Springhill Park		✓			✓				

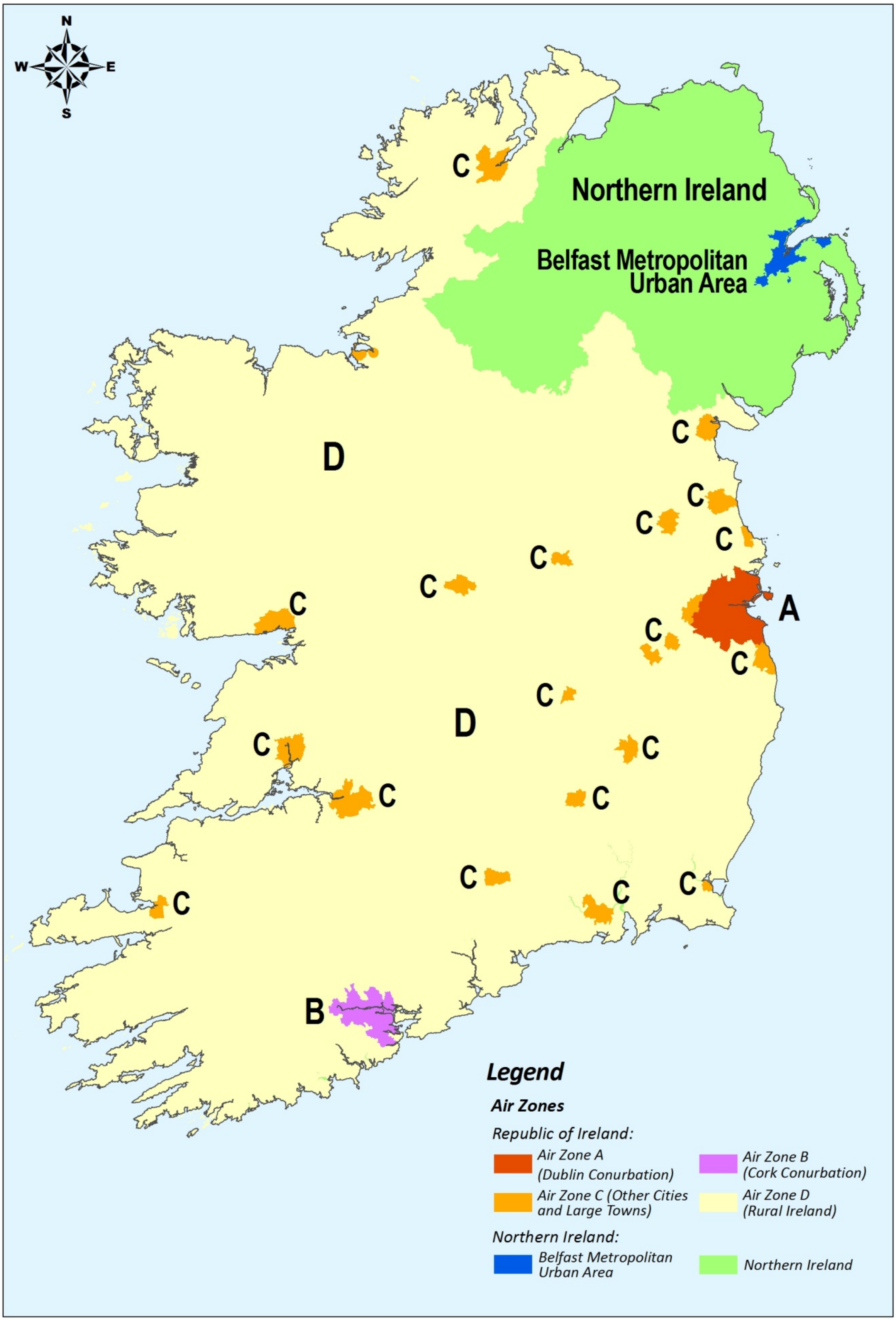

Figure 5.2. Air quality zones in Ireland and Northern Ireland.

5.3.2 Monitoring frequency, assessment threshold and pollutants

The Northern Ireland AMN currently consists of 22 automatic air quality monitoring stations (as shown in Figure 5.1), each equipped with continuous monitoring equipment for one or more of the pollutants for which automatic methods are used, including CO, NO_X, SO_2, PM_{10}, $PM_{2.5}$ and O_3 (DOENI, 2014, 2016). PAHs, including BaP, and benzene are also monitored.

Six of the automatic monitoring sites (Belfast Centre, Belfast Stockman's Lane, Derry Brooke Park, Armagh Lonsdale Road, Ballymena Ballykeel and Lough Navar) are part of the UK's national monitoring network, and are used to assess compliance with the Air Quality Directive. Belfast Stockman's Lane is the latest addition, having been "affiliated" into the national network in 2014.

Non-automatic monitoring techniques are used for benzene and PAHs, and some of these measurements are also used to assess compliance with the Air Quality Directive and the Fourth Daughter Directive.

5.3.3 Background air quality modelling

The monitoring programmes in Northern Ireland are supplemented by regional air quality modelling for NO_2, NO_x, PM_{10} and $PM_{2.5}$ to assist local authorities and support the review and assessment of local air quality. Two primary functions of air quality modelling include:

- the establishment of background concentrations, on a 1 km x 1 km resolution, that represent ambient air quality concentrations at background locations;
- the establishment of roadside concentrations, that is, the concentration of pollutants at the roadside of major urban road links (i.e. motorways and major A roads) throughout the UK.

Roadside concentrations are not modelled for CO, SO_2, O_3, BaP or metals, as the sources of these are not deemed to be significantly traffic related.

The models have been designed to assess compliance at locations defined by the Directives as relevant for air quality assessments (DEFRA, 2014).

The 1 km x 1 km background maps are made up of several components which are modelled separately and then added together to make the final grid. These individual components (supplemented by some additional components for various pollutants) are:

- large point sources (e.g. power stations, steel works and oil refineries);
- small point sources (e.g. boilers in town halls, schools and hospitals, and crematoria);
- distant sources (characterised by the rural background concentration);
- local area sources (e.g. road traffic, domestic and commercial combustion, and agriculture).

In order to ensure that these ambient concentrations from area sources are representative of the real world situation, they are validated against measurements taken from the national networks. After the validation has been completed, the large point source, small point source, distant source and validated area source components are added together to provide the final background map (DEFRA, 2014).

There are several benefits of using modelling to complement the monitoring data gathered across the UK monitoring networks:

- It allows coverage of the whole region rather than just the specific locations in which there is a monitoring site. A monitoring site might not fully represent the wider region in which it is located because of particular local characteristics, such as buildings, which affect dispersion, or localised or temporary sources.

- It provides a framework within which different air quality scenarios can be assessed. For example, it can be used to project concentrations in order to assess pollutant levels in future years, and to consider potential changes to emissions and, therefore, assess the likely impact of policy initiatives on air quality.
- It reduces the need for fixed continuous monitoring to comply with European Air Quality Directives, therefore ensuring value for money.

5.3.4 Naturally occurring radioactive materials

Radioactivity monitoring in Northern Ireland

The NIEA monitors radiation in the environment in Northern Ireland (see Figure 5.11). Samples of seaweed, sediment, fish, nephros and winkles are collected quarterly and forwarded for analysis. In addition to this programme, NIEA monitor the gamma dose rate in the air over intertidal sediments in each district council area that has a coastline (Environment Agency *et al.*, 2013). This monitoring programme has several purposes. Ongoing monitoring helps to establish the long-term trends in concentrations of radioactivity over time within the vicinity of, and at distance from, licensed nuclear sites, and the results are also used to confirm the safety of the food chain.

Periodic surveys on radon in dwellings in Northern Ireland are carried out to assess the exposure of the population of Northern Ireland to radon in dwellings (Health Protection Agency and Northern Ireland Environment Agency, 2009). According to the latest review by the Health Protection Agency, Radiation Protection Division (RPD), 84% of the average annual dose to the UK population from all sources comes from the four main components of natural ionising radiation (Watson *et al.*, 2005). The contributions to the total exposure of the population from the four natural sources of ionising radiation are as follows: 9.5% from long-lived natural radionuclides in the diet; 12% from cosmic radiation; 13% from terrestrial gamma radiation; and 50% from radon and its short-lived decay products.

Tellus and Tellus Border projects

Tellus is a regional mapping project which combines geophysical and geochemical surveys to provide world-class geoscientific information for the island of Ireland. Since 2007, over 25,000 km^2 of the island of Ireland has been surveyed through Tellus surveys, which support mineral exploration, environmental management, agriculture and research activity. Tellus continues as a programme area of the GSI, funded by the DCENR. The current survey phase, Tellus North Midlands, follows southwards from the border region survey and aimed to have completed airborne geophysics data acquisition and geochemical sample collection by mid-2015.

The survey included measurements of uranium, thoron and radioactive potassium. The uranium levels can be used as a proxy for radon, and the results show the distribution of naturally occurring radioactivity, which strongly correlates with bedrock geology and superficial deposits.

However, the presence and concentration of radon gas in homes is a function of its source, its transport to the surface, and the nature and construction of the building. The source of radon is associated with the local geology and the concentration of uranium within rocks and soils. For example, highly radioactive granitic rocks present within the region produce strong uranium anomalies and are associated with “radon highs”. However, although radon is a uranium derivative, it is important to note that simply mapping its distribution does not necessarily give an accurate indication of the levels of radon gas at the ground surface – which is critical for decision-making (Hodgson and Carey, 2014).

5.4 Monitored Compounds

The following sections describe the monitoring networks on a compound-by-compound basis for the air pollution compounds related to UGEE, with an overview of station location and monitoring results.

5.4.1 Nitrogen oxides and nitrogen dioxide

NO_2 levels across all zones (A, B, C and D) of Ireland have remained relatively static since 2003, with signs of a slight increasing trend in the years 2008–2010. During this period, NO_2 levels have been close to the limit value at Dublin and Cork city centre monitoring sites, and the limit value was exceeded in Dublin in 2009. However, NO_2 levels decreased in 2010, 2011 and 2012. This downwards trend may have stabilised in 2013. The reason for the decrease in NO_2 concentrations in 2010, 2011 and 2012 could partly be as a result of meteorological conditions. Cold and dry or warm and dry periods of weather with stable airflows lead to a build-up of pollutants such as NO_2. High NO_X emissions within urban centres may lead to an exceedance of the limit value in the future because of the continued reliance on motorised vehicles (EPA, 2014).

In Northern Ireland, levels of NO_2 (due to transport) remain an issue, with monitored levels at particular locations exceeding objectives (NIEA, 2013).

Figure 5.3 and Figure 5.4 show the monitoring networks across the island of Ireland for NO_X and NO_2. Both Dublin and Belfast have several monitoring stations in various parts of the cities, although the network is more sparse for the more rural areas, particularly in the western counties, reflecting the fact that elevated levels of NO_X and NO_2 tend to be associated with urban areas and the associated traffic.

This indicates the importance of local baseline measurements for NO_X and NO_2 prior to the commencement of any UGEE activities, as, typically, large numbers of heavy goods vehicles (HGVs) are required during the UGEE process. Accurate baseline measurements are needed in order to estimate the impact of increased traffic levels. In Northern Ireland, modelled background measurements are available; however, verification of the modelled levels through monitoring is preferable. Proposed monitoring programmes are set out in Chapter 7.

5.4.2 Sulfur dioxide

Levels of SO_2 are low in Ireland and are below all relevant limit and target values (EPA, 2013), in common with the rest of Europe where SO_2 levels have been decreasing since the 1990s. In Northern Ireland, the data show that the annual average concentrations of SO_2 have declined to low levels. This is because of the impact of the implementation of European directives on low-sulfur fuel (smokeless coal, low-sulfur or sulfur-free fuel oil, etc.) and the switching from coal to gas in the domestic sector. The implementation of the requirements of the Large Combustion Plant Directive has also reduced SO_2 emissions (NIEA, 2013).

Figure 5.5 shows the existing SO_2 monitoring network. SO_2 is not typically associated with UGEE processes, unless flaring is carried out, which can convert hydrogen sulfide (H_2S) into SO_2. Best practice now includes RECs, or “green completions”, meaning that SO_2 emissions are increasingly unlikely. Therefore, reference to national levels is considered adequate for the characterisation of local air quality for air quality assessments related to UGEE activities.

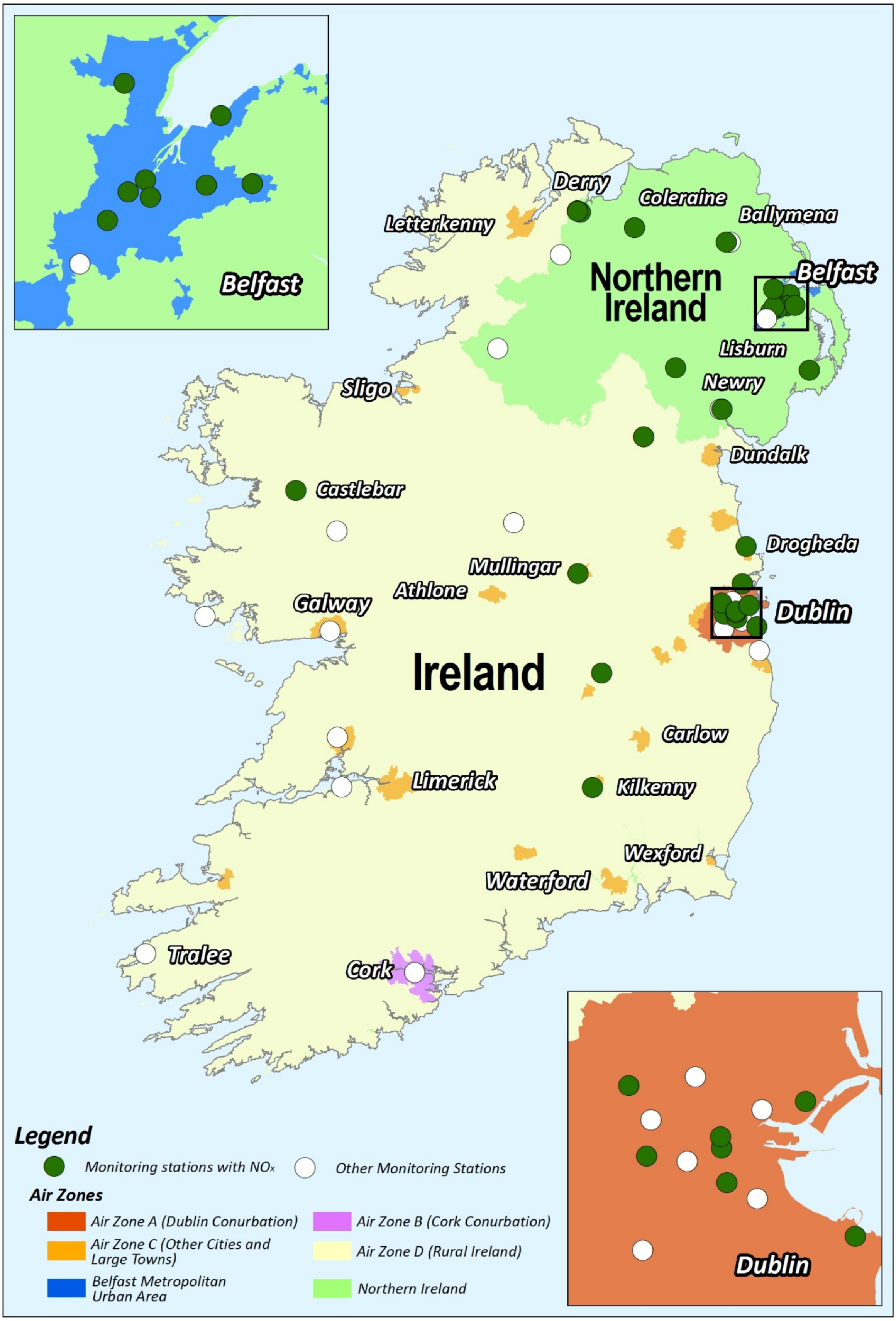

Figure 5.3. NO_x monitoring stations in Ireland and Northern Ireland.

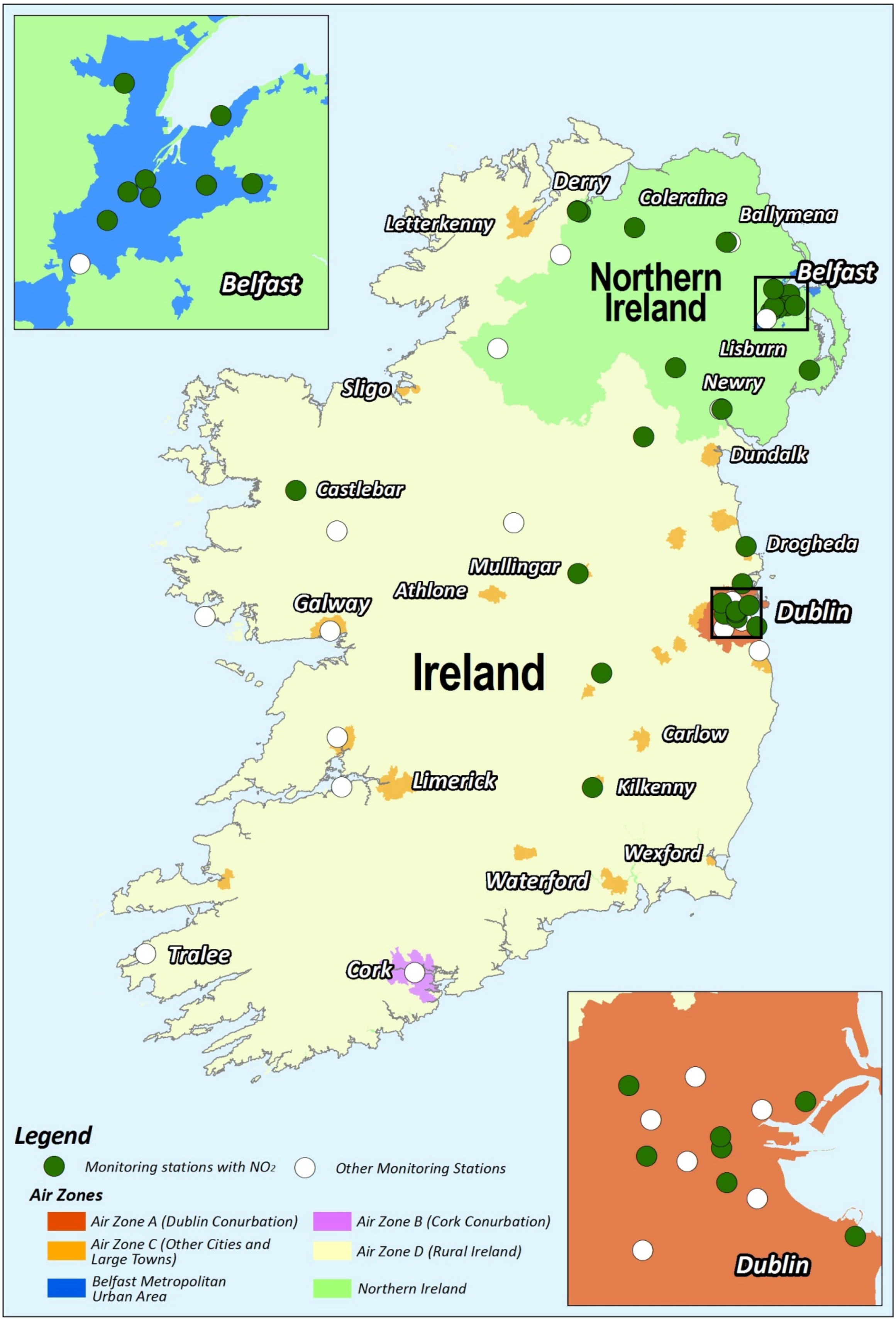

Figure 5.4. NO_2 monitoring stations in Ireland and Northern Ireland.

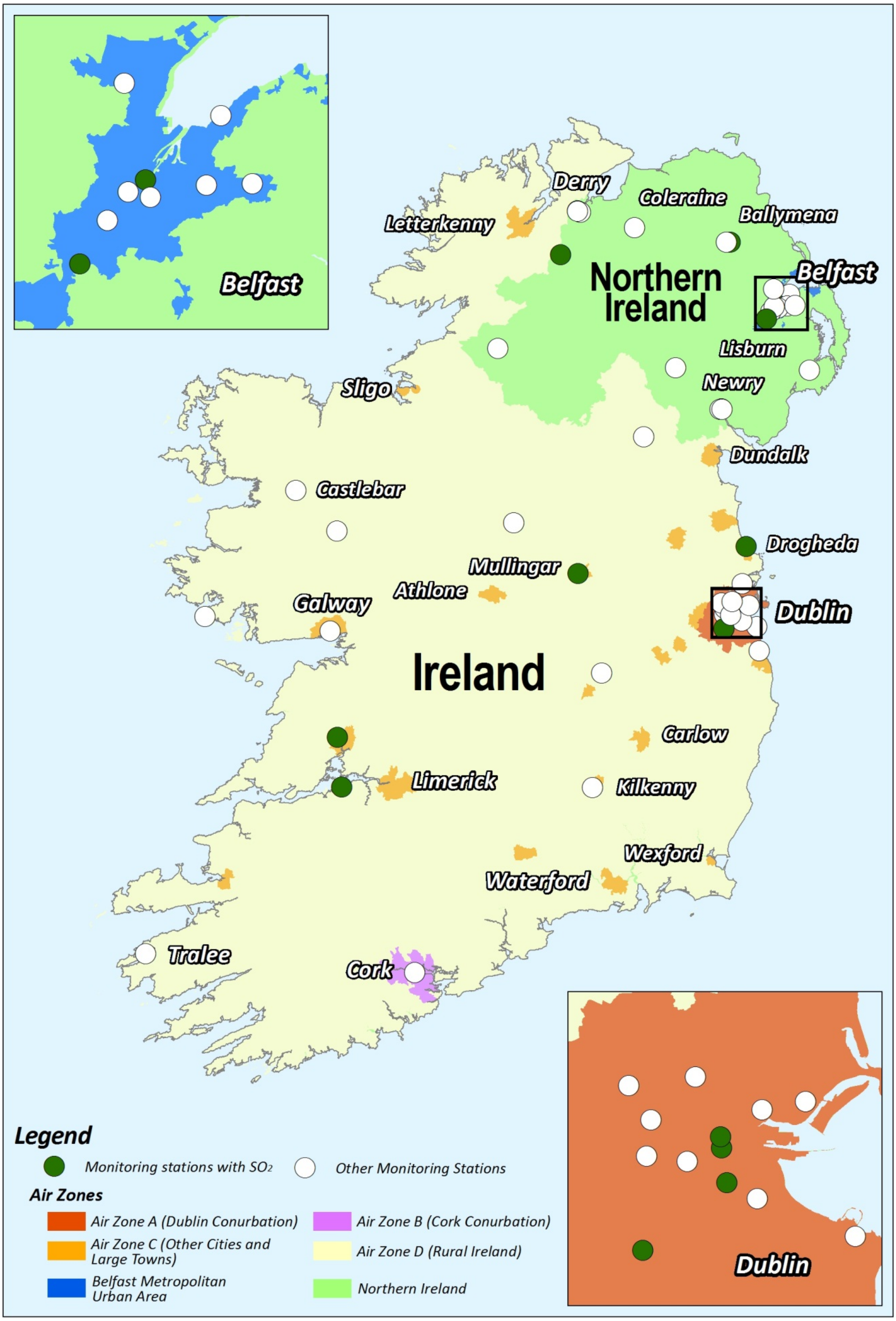

Figure 5.5. SO_2 monitoring stations in Ireland and Northern Ireland.

5.4.3 Carbon monoxide

The CO monitoring network is shown in Figure 5.6. CO was monitored at one station in Northern Ireland and five stations in Ireland. All measurements were well within the EU limit value and Air Quality System objective, and have been for many years. Elevated levels of CO are not associated with UGEE processes, nor is CO relevant for the assessment of national road schemes (NRA, 2011). As a result, monitoring in order to characterise background CO levels is not critical, and reference to national levels is considered adequate for the characterisation of local air quality for air quality assessment of UGEE activities.

5.4.4 Ozone

Figure 5.7 shows the ozone monitoring network in Ireland and Northern Ireland. O_3 is a powerful oxidising agent and can affect health and vegetation. The emission of O_3 precursors, such as NO_X, CO and VOCs, is associated with UGEE activities.

Epidemiological studies show that there are short-term effects of O_3 on mortality and respiratory morbidity, and provide information on exposure–response relationships and effect modification. In addition, epidemiological and experimental evidence shows that long-term elevated concentrations of O_3 can cause lung damage and inflammatory responses (WHO, 2003, 2006).

O_3 is one of the air pollutant species that is identified as a transboundary pollutant by the Task Force on Hemispheric Transport of Air Pollution, under the United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution (CLRTAP). Modelling and measurement studies have shown that baseline surface O_3 levels in Europe are changing with time and are not consistent with changes in emission levels of O_3 precursors on a regional scale (Tripathi *et al.*, 2010).

Short, acute O_3 pollution episodes are infrequent in Ireland; however, they have happened in the past and will happen in the future. They are most likely to occur in summer months if there is a stable anti-cyclone over Ireland, which brings settled, warm weather. The movement of polluted air masses from Europe is more likely to occur during these periods, and these air masses are likely to contain high levels of O_3. Because O_3 levels in Ireland are highly influenced by transboundary sources, the attainment of the long-term objective and compliance with the WHO guideline value will occur only if hemispheric O_3 levels reduce.

This means that local authorities may have little control over O_3 levels in their area (NIEA, 2013) and reduction of O_3 levels will require a European, and possibly a global, effort to reduce emissions of O_3 precursors (EPA, 2014). Therefore, the existing O_3 monitoring network is considered adequate for ambient air baseline characterisation purposes and no additional monitoring is considered necessary.

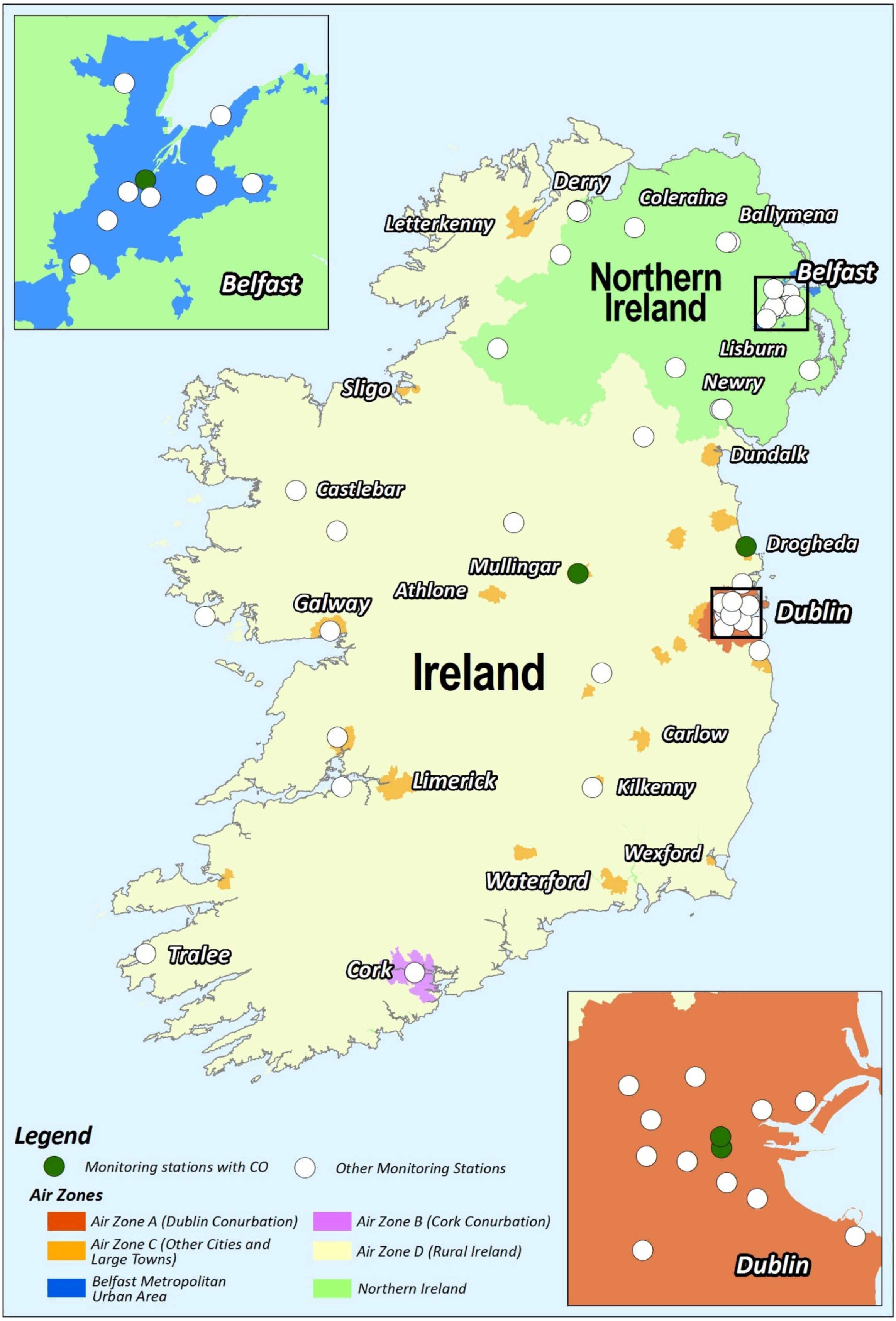

Figure 5.6. CO monitoring stations in Ireland and Northern Ireland.

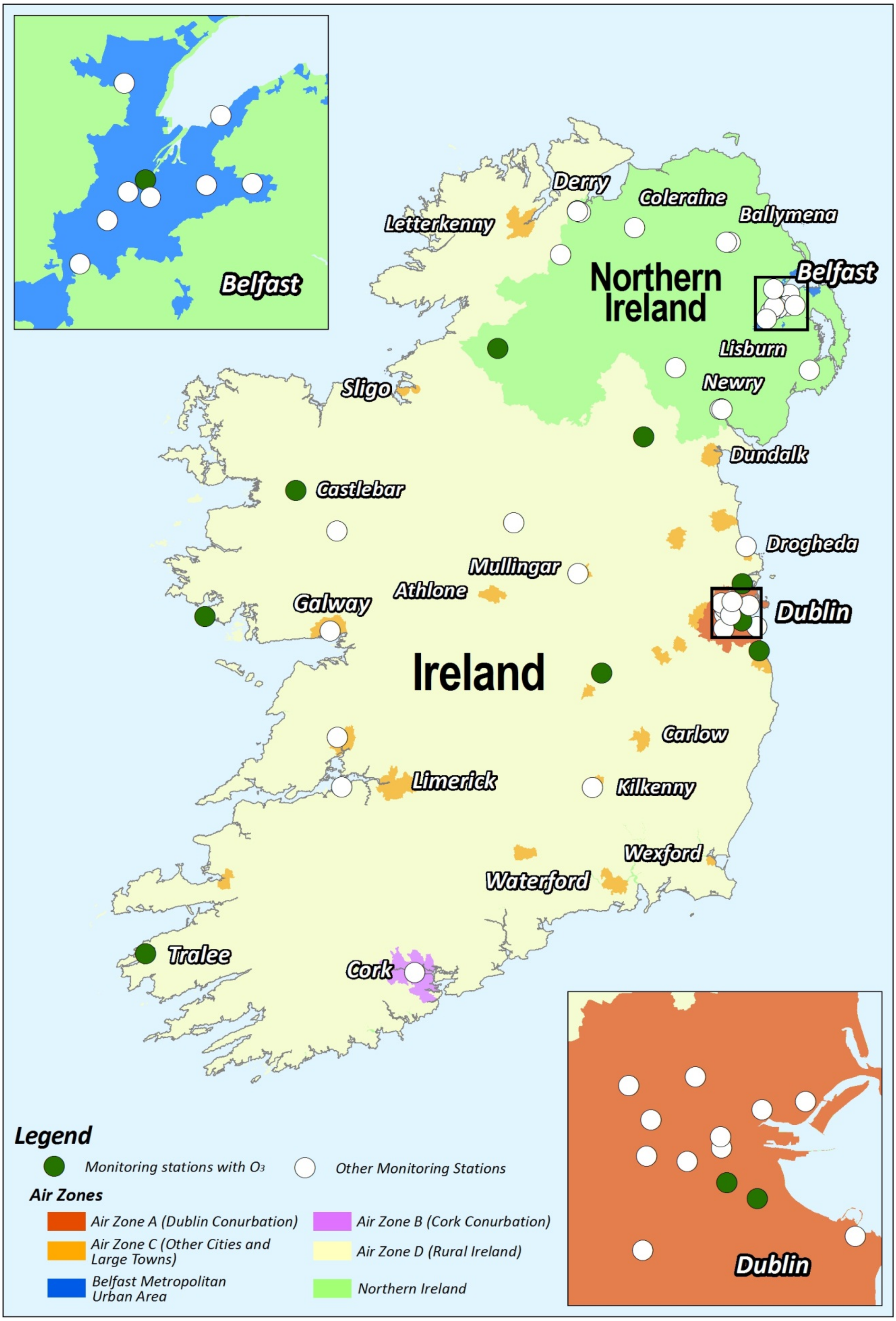

Figure 5.7. O_3 monitoring stations in Ireland and Northern Ireland.

5.4.5 Particulate matter (PM_{10} and $PM_{2.5}$)

Figure 5.8 shows the PM monitoring network. In general across the island of Ireland, PM_{10} concentrations show a decreasing trend in cities and large urban areas. This is mainly because of decreases in particulate emissions from traffic, arising from improvements in vehicle engine emissions. However, this decrease is not seen in smaller towns in which domestic solid fuel emissions are more significant than traffic emissions. Many towns do not benefit from the ban on smoky coal, and often do not have access to cleaner fuel alternatives, such as natural gas (EPA, 2012).

Although the PM monitoring network is comparatively comprehensive, PM is closely linked to increases in vehicular transport, as reflected by it being one of the pollutants that is recommended for assessment of national road schemes (NRA, 2011).

There is a close, quantitative relationship between exposure to high concentrations of small particulates (PM_{10} and $PM_{2.5}$) and increased mortality or morbidity, both daily and over time. Conversely, when concentrations of small and fine particulates are reduced, related mortality also declines, presuming that other factors remain the same. This allows policymakers to project the population health improvements that could be expected if particulate air pollution were to be reduced.

Small particulate pollution has health impacts, even at very low concentrations. Indeed, no threshold has been identified below which no damage to health is observed (WHO, 2005). Therefore, daily and annual limits are set in Europe under the CAFE Directive, and the WHO 2005 guideline limits aim to achieve the lowest concentrations of PM possible.

Local monitoring to establish background levels is therefore necessary to enable a complete assessment of potential impacts arising from UGEE activities, including the increase in vehicular traffic, and any increase in PM levels from site operations. Proposed specifications for this monitoring are given in Chapter 7.

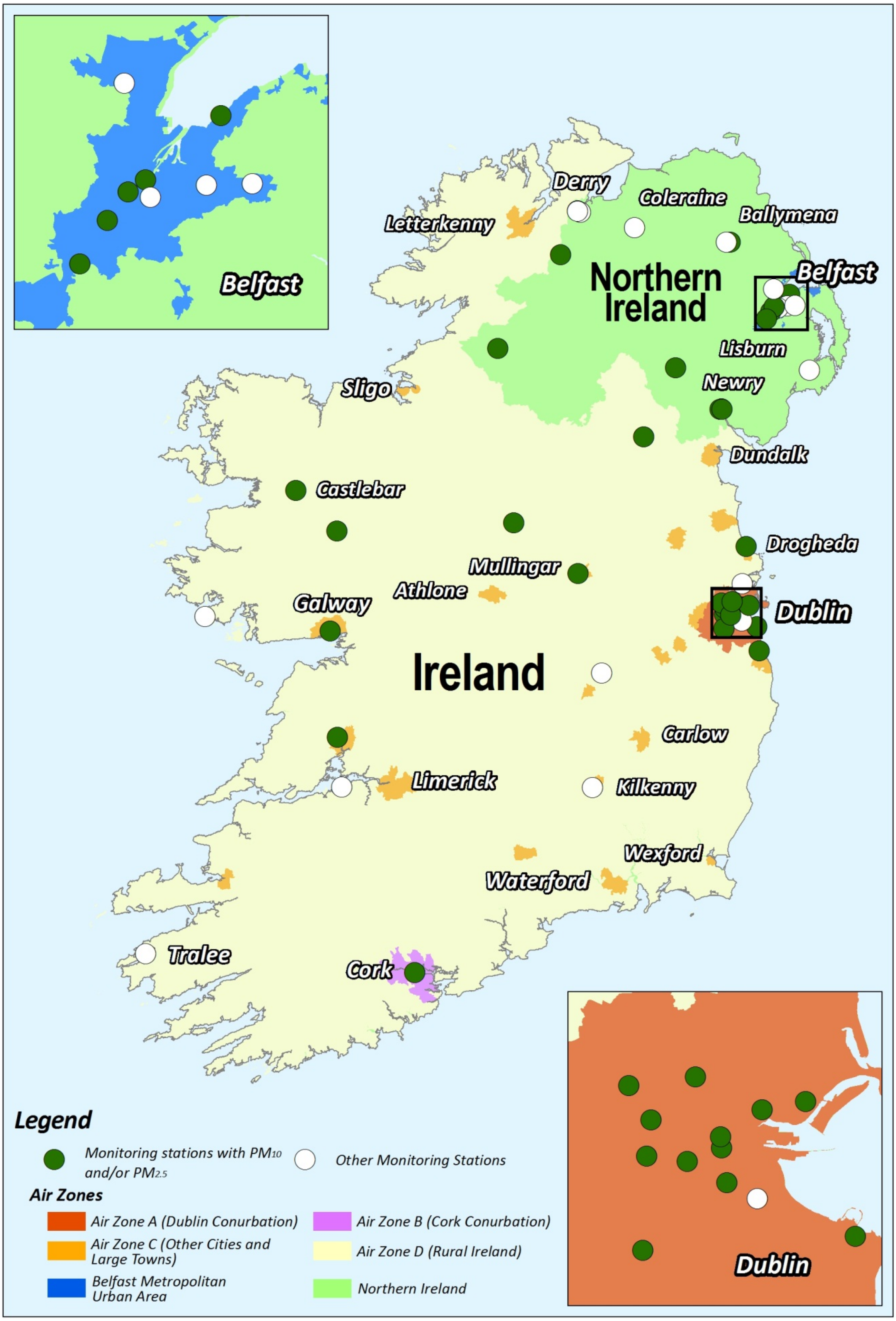

Figure 5.8. PM monitoring stations in Ireland and Northern Ireland.

5.4.6 Benzene and volatile organic compounds

Figure 5.9 shows the benzene monitoring network. Benzene is linked to both automobile emissions and well completion activities associated with UGEE, although benzene emissions can be significantly reduced through “green completion”. UGEE activities are also linked to elevated levels of a range of other VOCs, including toluene, ethyl-benzene and xylenes. Table 4.13 shows the CAFE Directive limit values for benzene; however, the WHO does not set a limit because benzene is a carcinogen and, therefore, there is no limit for benzene that can be, categorically, considered safe. There are also no limits set for ambient levels of the other relevant VOCs.

While VOCs, such as toluene, xylene, ethylbenzene, m- and p-xylene, and o-xylene, have been measured at locations including Rathmines in Dublin, it is critical that local monitoring be carried out to fully characterise background levels, and enable the assessment of their impact before any UGEE operations commence. Proposed specifications for monitoring are given in Chapter 7.

*5.4.7 Benzo[*a*]pyrene and polycyclic aromatic hydrocarbons*

Along with VOCs, PAHs form another major group of organic pollutants in the air. Elevated levels of PAHs have been associated with UGEE activities (Colorado School of Public Health, 2011), underscoring the importance of including PAH monitoring as part of any baseline monitoring study.

PAH monitoring is based on the premise that one particular compound can be used as a marker for all PAHs. The EPA monitor PAH levels as a fraction of PM_{10}, and PAH levels were first measured in 2009; this will provide a good baseline for the comparison of local monitored levels with national data. The location of the monitoring stations that monitor BaP (and other PAHs) are shown in Figure 5.10. Because of the limited number of stations that monitor BaP, and the potential negative health impacts, local monitoring of background levels is advised. Proposed specifications for monitoring are given in Chapter 7.

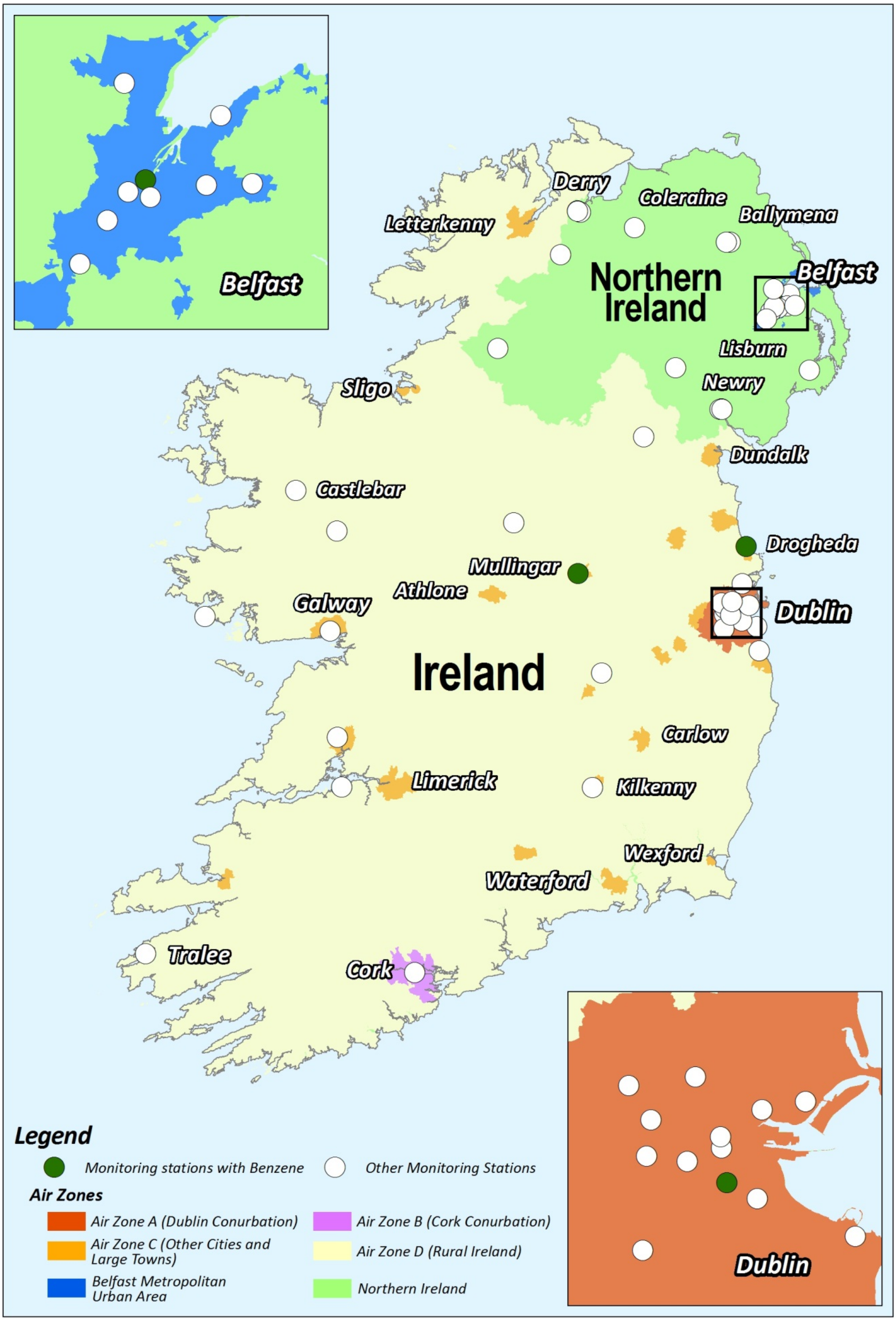

Figure 5.9. Benzene monitoring stations in Ireland and Northern Ireland.

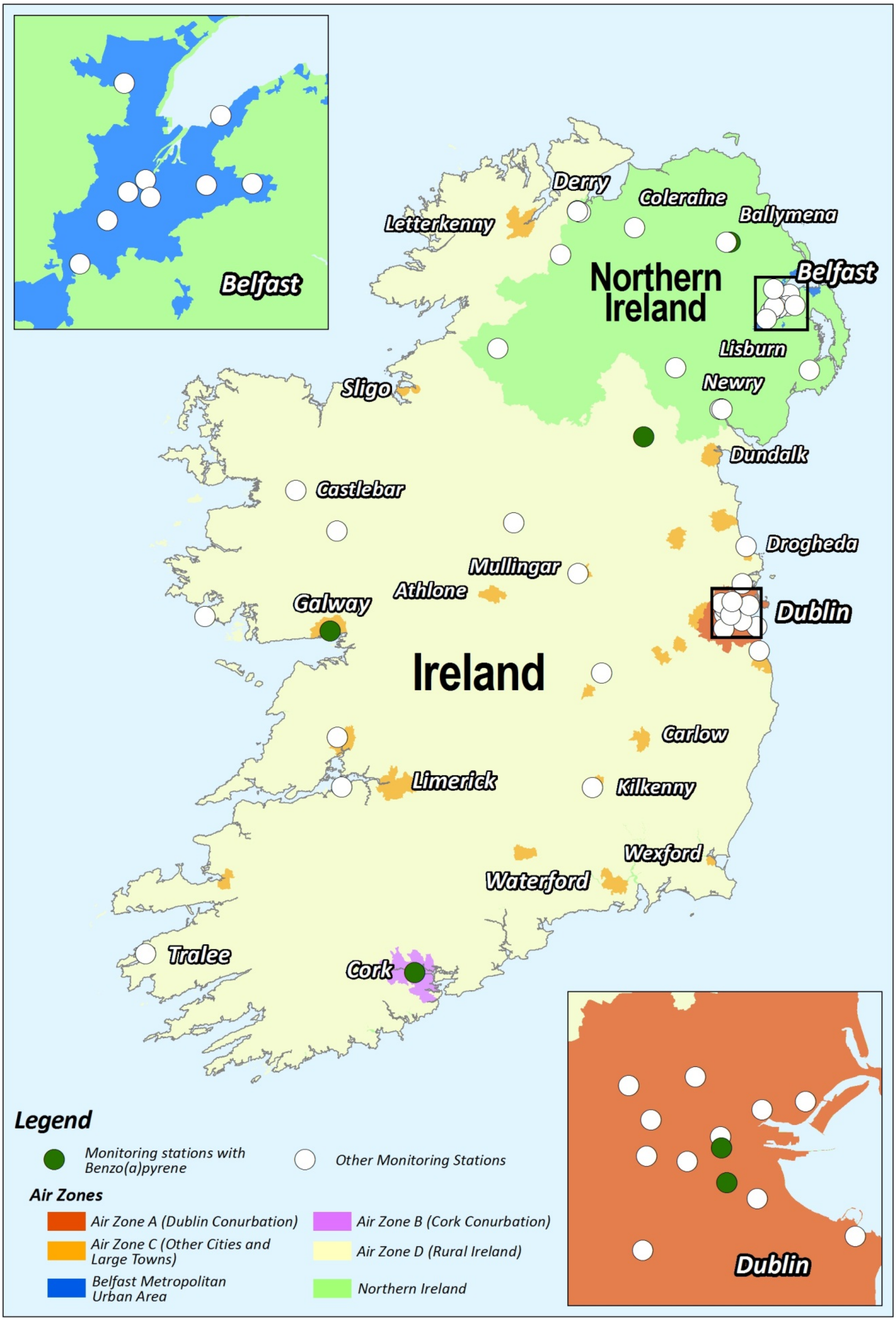

Figure 5.10. BaP monitoring stations in Ireland and Northern Ireland.

5.4.8 Naturally occurring radioactive materials

The locations of radioactivity monitoring sites are shown in Figure 5.11. As discussed in section 3.3.1, UGEE processes may result in emissions of radon at the wellhead. Extensive surveys of radon have been undertaken across the island of Ireland (Health Protection Agency and Northern Ireland Environment Agency, 2009; RPII, 2012); however, these surveys focused on the indoor exposure to radon in domestic dwellings.

Based on the Tellus and Tellus Border projects, potential radon risk has been modelled on a 1-km-grid scale using information on airborne uranium, the groundwater recharge coefficient and the degree of karstification of the mapped bedrock. In general, the model shows good agreement with the existing National Radon Map produced by the RPII, but at an improved resolution. However, previously unknown radon highs are predicted in certain areas, including central Sligo and Leitrim, southern Donegal and a band running through northern Monaghan.

As a result, it is proposed that monitoring of radon be carried out to accurately establish background levels outdoors in the study area. Proposed specifications for monitoring are given in Chapter 7.

5.4.9 Methane

Increased atmospheric concentrations of greenhouse gases, such as methane, which are released by human activities, trap additional energy in the Earth's climate system. This is known as "global warming" and it is believed to be causing a range of Earth system changes, broadly referred to as climate change. The resultant impacts include an increase in the average global temperature, the loss of snow and ice cover, and a rise in the global sea level.

Therefore, assessment of UGEE processes and the associated methane emissions generally focus on the life cycle emissions of methane, as opposed to the ambient background levels and the associated health risks of exposure to ambient levels. This approach is further supported by the European Commission's greenhouse gas monitoring mechanism, under which the reporting of methane emissions is required, the annual submission requirements of the United Nations Framework Convention on Climate Change, and the reporting of methane emissions within the Kyoto Protocol as one of the "basket of six". As a result, there is no network of ambient methane monitoring stations.

Nonetheless, in order to accurately monitor and estimate life cycle emissions, it would be beneficial to establish a baseline level against which increases could be measured. This is particularly important in light of recent studies showing that one small "hot spot" in the Southwestern United States is responsible for producing the largest concentration of methane in the USA – more than three-fold higher than the standard ground-based estimate (Kort *et al.*, 2014). This highlights the need for better monitoring of methane levels during the operational phase of UGEE. Proposed specifications for monitoring are given in Chapter 7.

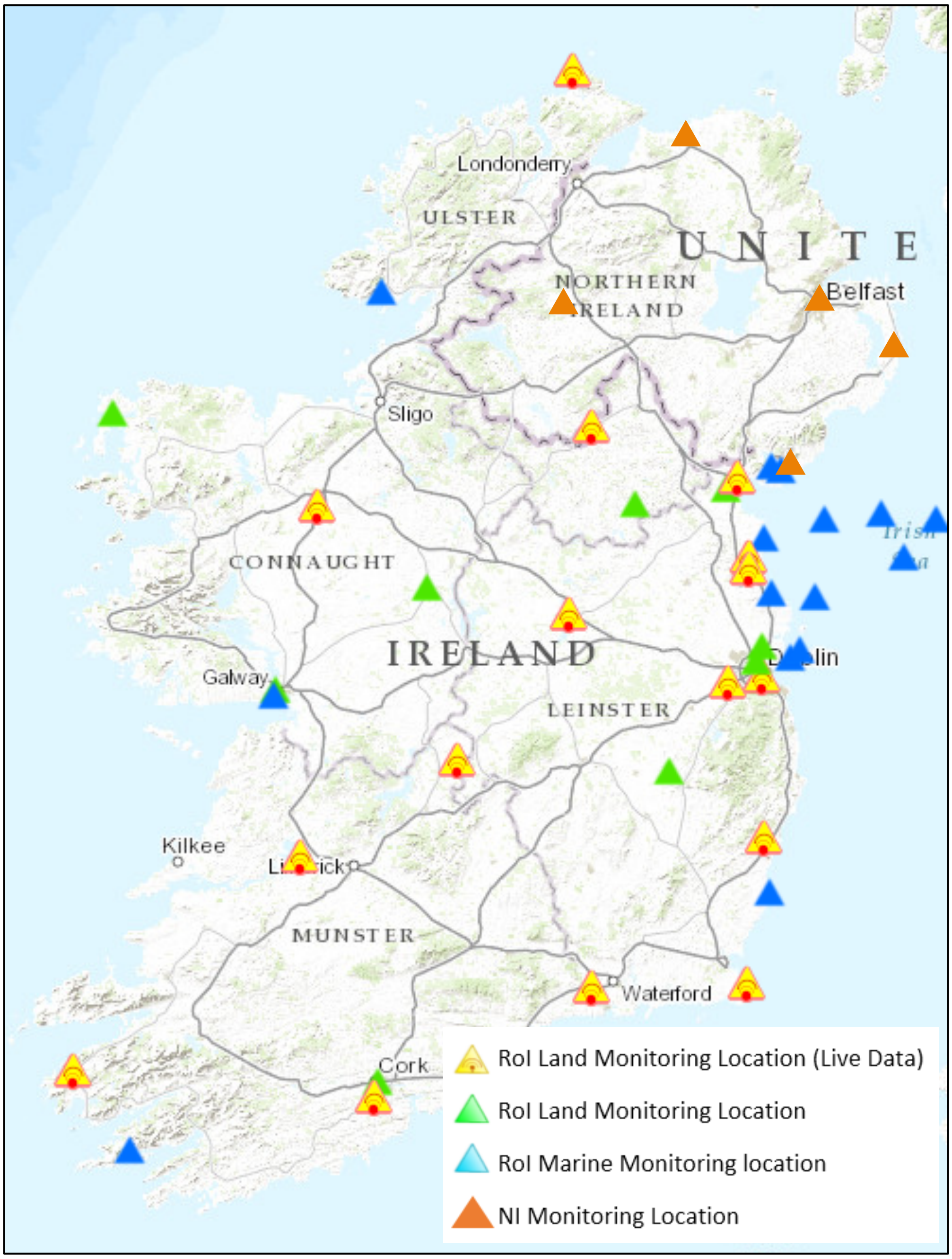

Figure 5.11. Locations of radioactivity monitoring sites.

6 Review of International Requirements and Baseline Characterisation

6.1 Introduction

This section reviews the background and requirements of a selection of varying jurisdictions with respect to air quality, specifically, the characterisation of air quality baselines related to UGEE activities.

6.2 The European Union

In Europe, the extraction of shale gas is currently in its exploratory phase. Low numbers of exploratory wells have been drilled, and Spencer *et al.* (2014) reported that, as of February 2014, approximately 50 wells had been drilled. As a result, the current legislative framework in the EU was largely drafted for the exploration and exploitation of conventional gas deposits. The components of this framework, including definitions, concepts and permit procedures, may sometimes not correspond to the specifics of unconventional gas, including shale gas (JRC, 2012).

With respect to unconventional gas extraction processes, the European Commission adopted a non-binding Recommendation (as defined in Article 288 of the Treaty on the Functioning of the European Union) on January 22, 2014, that includes the minimum principles that EU Member States should consider if applying or adapting their legislation to hydrocarbon exploration or production using high-volume hydraulic fracturing. The Recommendation is intended to complement existing EU legislation and suggests the need for strategic environmental assessments (SEAs) before any fracturing operations, likely to use more than 10,000 m^3 of water, are permitted. SEAs require the consideration of the impacts of proposed plans and programmes, likely to have a significant impact on the environment, on air quality (under SEA Directive 2001/42/EC), which in turn requires the characterisation of baseline air quality. However, specific requirements for baseline characterisation are not detailed.

The language used in the Recommendation is quite broad. For example, it suggests that hydraulic fracturing operators should be required to establish an environmental baseline for:

- air quality;
- the quality and flow characteristics of surface and groundwater;
- the water quality at drinking water abstraction points;
- soil conditions;
- the presence of methane and other VOCs in water;
- seismicity;
- land use;
- biodiversity;
- the status of infrastructure and buildings;
- existing wells and abandoned structures.

With respect to air emissions, the Recommendation states only that Member States should ensure that operators "capture gases for subsequent use, minimise flaring and avoid venting. In particular, operators should put in place measures to ensure that air emissions at the exploration and production stage are mitigated by capturing gas and its subsequent use. Venting of methane and other air pollutants should be limited to the most exceptional operational circumstances for safety reasons".

The Commission adopts a considerably more flexible approach to shale gas regulation in the EU in their Recommendation than had been under consideration at various points during the drafting of this regulation (Baker & Mackenzie, 2014). The European Commission initially considered adopting a binding EU-level law on shale gas developments. Similarly, in October 2013, the European Parliament proposed changes to the EU impact assessment rules that would have required completion of an impact assessment for shale gas extraction, but not for initial exploration. However, this proposal was amended, and EIAs for shale gas are no longer mandatory.

The implementation of the Recommendation is not mandatory, but Member States allowing shale gas development are required to report to the European Commission annually about the measures they put in place in response to the Recommendation. The European Commission will monitor implementation of the Recommendation and maintain a publicly available “scorecard” that tracks country-level compliance.

6.2.1 The UK

The UK is arguably one of the best-informed Member States in that it was among the first to carry out detailed assessments, including a study which concluded that there is no direct risk to water aquifers, as long as the well-casing is intact. However, seismic activity near Cuadrilla’s drilling site in Blackpool, in North West England, in April/May 2011 (Green *et al.*, 2012) has given rise to concern, and led to a temporary moratorium on activities, which was subsequently lifted in December 2012.

The lifting of the UK-wide moratorium was subject to new controls to mitigate the risks of seismic activity. These new controls include a traffic light system to categorise seismic activity and direct appropriate responses (DECC, 2014b). At the same time, the UK Government announced that there would be a consultation on how the current licensing regime could be modified to support the particular characteristics of shale gas developments, and that a tax regime specific to the shale gas industry would be developed (Shepherd, 2013).

In July 2013, the UK Government published a consultation paper on proposals for a tax regime for shale gas. In this consultation paper, the UK Government recognises the potential for shale gas to increase energy security, create jobs and generate substantial tax revenue. The proposals in the consultation aim to unlock early investment and support industry development. At the end of July 2013, draft technical guidance for onshore oil and gas exploratory operations was released for public consultation. Guidance on how shale gas (and other onshore oil and gas) developments should proceed through England’s planning system was also published.

In addition, in December 2013, a new tax allowance to kick start the exploitation of onshore oil and gas (including shale gas) was announced. This allowance makes the effective tax rate for shale gas projects lower than that in the USA and the most competitive in Europe.

In July 2014, the UK Government announced the launch of the 14th onshore licensing round. The details, including planning guidance for areas of outstanding natural beauty, national parks and world heritage sites, were set out by the Department of Energy and Climate Change (DECC) (Hutton and Bakhsh, 2014).

The United Kingdom Onshore Operators Group (UKOOG) (the representative body for UK onshore oil and gas companies including those involved in exploration, production and storage) has published industry guidelines on best practice for shale well operations during the exploration and appraisal phase in the UK (UKOOG, 2013). DECC, the UK Health and Safety Executive, the Environment Agency (EA) and the Scottish Environment Protection Agency (SEPA) contributed to these guidelines. These guidelines do not address baseline air quality characterisation but recommend that operators eliminate all unnecessary flaring and venting of gas, implement best practices from the early design stages of the development and endeavour to improve on these during the subsequent operational phases. The guidelines further recommend that emphasis be placed on “green completions” for cases in which there are practicable.

The concerns to date have been focused primarily on potential impacts on water resources and seismic activity. UKOOG entered into a memorandum of understanding with Water UK (which represents the UK water industry) to ensure their members co-operate during shale gas exploration and extraction processes (Water UK and UKOOG, 2013). The key aim of the memorandum is to give the public confidence and reassurance that everything will be done to minimise the effects of hydraulic fracturing on water resources and the environment.

Overall, the UK government remains positive towards UGEE activities and, while the legal framework is being clarified, the UK appears to believe that further EU legislation on shale gas activity is unnecessary (Shepherd, 2013). Public debate regarding onshore hydrocarbon production (both conventional and unconventional) has increased, and there have been high profile protests highlighting the public concern about hydraulic fracturing. No specific direction on baseline or operational air quality monitoring have been produced; the existing legislative framework is deemed sufficient to determine and manage potential impacts on air quality.

The Scottish Government, however, announced a moratorium on all planning consents for UGEE projects in January 2015. Full control over the process is expected to be devolved to Scotland after the general election in the UK in 2015.

In addition, the Welsh National Assembly ministers are backing a motion against UGEE activities. If powers over licensing are devolved to the Welsh Assembly, a moratorium on UGEE activities is expected to be put in place (WalesOnline, 2015).

6.2.2 Poland

Poland is another front-runner with regard to shale gas development in the EU. This is because of a combination of political will and the potentially favourable geology in Poland. Poland is currently dependent on Russia for its crude oil and natural gas, and the development of shale gas is considered, by the Polish authorities, to be a key component of its strategy to diversify Poland’s energy mix and improve its energy security (Shepherd, 2013).

The Polish Geological Institute (PGI) released a report in June 2012 which suggests that there could be up to 1.9 trillion m^3 of recoverable shale gas reserves (PGI, 2012). However, more recent reports have suggested that these reserves may not be quite as large as estimated by the PGI, and the US Energy Information Administration has reduced its previous estimate of Poland’s shale gas reserves by 20%. Although exploratory wells have been drilled, none is producing gas in commercially viable quantities (Foy, 2014).

In Poland, the permitting process takes, on average, 8 months, whereas in Pennsylvania, USA, it takes only 45 days, according to Pawel Poprawa (AGH University of Science and Technology, Krakow, as reported by Strzelecki and Almeida (2014)), and the Act on Mining and Geological Law of 9 June 2011 (Journal of Laws of 2011, No. 163, item 981, as amended) is the main instrument that currently governs the process of shale gas exploration and exploitation. With respect to air quality legislative requirements, the Act on Mining and Geological Law, the Ministerial Ordinance on Environmental Impact Assessment 2008 and the Law on Environmental Protection 2001 address flaring in the context of shale gas activities. Gas that will not be marketed and exceeds operational requirements can be flared without obtaining consent from the Ministry of Environment (Baker & McKenzie, 2014).

In June 2014, the European Commission sent Poland formal notice that it was opening a case against it for infringing the EIA Directive. The case relates to the fact that Poland amended its national laws to allow shale drills at depths of up to 5000 m without first having assessed the potential environmental impacts. In its defence, Poland is reported to have said that an amendment to its EIA law in June 2013 limits shale drills in “sensitive” areas, such as Natura 2000 sites, to depths of 1000 m. However, a spokesperson for the Environment Commissioner, Janez Potocnik, is reported to have responded by saying that, as shale gas reserves in Poland are located mostly at a depth 1000–4500 m, and the “sensitive” areas cover only 23% of Polish territory, the new thresholds de facto exclude most shale gas exploration projects in Poland from the scope of the EIA Directive (Neslen, 2014).

No baseline air quality assessment or characterisation is required or has been carried out in Poland, and no recommendations for baseline assessments have been made other than those under the SEAs or EIAs that may potentially be required under EU law.

6.2.3 Germany

After the nuclear disaster at Fukushima, Japan, in 2011, the German government made a major decision to phase out nuclear energy by 2022, rather than increase the use of it as previously planned. Prior to the federal elections in September 2013, progress was made in Germany to develop draft legislation to regulate hydraulic fracturing. The draft legislation clarified that hydraulic fracturing is, in principle, permitted in Germany other than in areas which are or are planned to become water protection areas (Vetter, 2014).

After the decision in June 2013 to not introduce a bill on the regulation of fracking technology within the previous parliamentary term, the Federal Environment Ministry and the Federal Economics Ministry presented a combined framework document in July 2014 (Federal Environment Ministry (Germany), 2014).

The combined framework document sets out key principles related to the regulation of fracking. These are the most stringent principles to date in Germany with respect to fracking activities. The proposed regulations distinguish between fracking for shale gas, found in hard shale formations (except for experimental fracks), and fracking for tight gas, which is found in dense sandstone and limestone at depths of 3500 m or greater

Fracking projects to extract gas from shale and coal bedrock formations above 3000 m are banned under the Water Resources Act, until at least 2021 at which time the legislator will review the appropriateness of the ban based on a federal government report about the state of science and technology specifically related to fracking. Fracking for tight gas (conventional fracking) will continue to be allowed in principle. Such projects have been carried out in Germany since the 1960s. Fracking for tight gas will not be allowed in Natura 2000 areas to ensure the protection of these areas designated as sensitive under the Habitats Directive.

With respect to air quality, the key principles specify that the following conditions will apply to all projects:

- Comprehensive EIAs must be performed for all deep drilling.
- A comprehensive initial state report must be drawn up.

These key principles will inform a number of legislative changes, in particular an amendment to the Water Resources Act and an amending regulation to the EIA for mining. However, at present, no specific requirements relating to the procedures or scope of the initial state report have been specified or documented.

In addition, there remains a general consensus among all the parties involved (citizens, public authorities, environmental associations, the science community and also the industry) that intensive research on all aspects of the topic of shale gas is required (Vetter, 2014).

6.2.4 France

According to a US Energy Information Administration study (EIA, 2013), France has technically recoverable reserves of 3.8 trillion m^3. In this study of 14 European countries, France was found to be second only to Poland with regard to its volume of shale gas deposits, and to have significantly larger reserves than Romania, which was the country with the next largest reserve volume (1.4 trillion m^3).

In France, activities related to shale gas were suspended in July 2011, with a ban on the exploration and exploitation of hydrocarbons by hydraulic fracturing and the cancellation of exploration permits that had been granted. It has since been confirmed that this decision will apply throughout President Hollande's 5-year term in office. However, it has been stressed that if other techniques for shale gas extraction were developed, this decision could be reassessed (Shepherd, 2013).

Despite politicians, experts and industry continuing to debate the merits of extracting shale gas and the publication of a number of pro-shale gas reports (including reports produced by the French Parliamentary Office for Scientific and Technological Choices and the Academy of Sciences (Office Parlementaire d'évaluation des Choix Scientifiques et Technologiques, 2013)), France is no further forward in exploiting its shale gas potential. At the beginning of October 2013, the French Constitutional Court rejected a challenge to the exploration ban imposed in 2011. The Court noted that, given the current state of scientific knowledge, the ban was not disproportionate (Shepherd, 2013).

No air quality characterisation activities relating to UGEE activities are currently specified or ongoing in France.

6.3 South Africa

The US Energy Information Administration estimates that South Africa has 1.1 billion m^3 of technically recoverable shale gas (EIA, 2013), placing it eighth on the list of countries with the world's largest shale gas resources. South Africa's Karoo Basin covers nearly two-thirds of the country and is thought to hold the largest shale gas reserves in South Africa.

The South African Government introduced a moratorium on licensing and exploring for shale resources in April 2011 as a result of concerns over the environmental effects of fracking and water usage.

Subsequently, in September 2012, the South African Government accepted recommendations from the Department of Mineral Resources (DMR) and lifted the moratorium on shale gas exploration (Accenture, 2012). However, the Minister of Mineral Resources indicated that although the moratorium had been lifted, pending exploration right applications would not be processed and awarded until regulations regarding unconventional gas exploration had been published. The proposed regulations entitled "Proposed technical regulations for petroleum exploration and exploitation" were published, for comment, in the *Government Gazette* of South Africa (Notice 1032 of 2013), on 15 October 2013 (DMR, 2013).

The regulations provide mechanisms for the assessment of the potential environmental impact of any proposed activities, for the protection of fresh water resources and for the co-existence of shale gas exploitation and the Square Kilometre Array (SKA) telescope project.

The regulations address the issue of air quality with respect to the minimisation of emissions. In addition, the regulations require that an environmental assessment be carried out covering, among other things:

- the characterisation and knowledge of the environmental pathways along which the impact could migrate;
- the characterisation and knowledge of the receptors that experience the impact;
- the development of a conceptual model.

These regulations infer that a baseline characterisation should be carried out, but no explicit details are set out.

However, a research programme aimed at determining the environmental baseline of the Karoo region has recently commenced. Nelson Mandela Metropolitan University and the Eastern Cape Department of Economic Development, Environmental Affairs and Tourism (DEDEAT) started a 3-year research project focusing on the viability of shale gas exploitation in the Karoo in March 2014. A main focus of this research programme is to produce a “natural baseline” for the Karoo.

With the lifting of the moratorium on exploration, international energy companies are expected to soon begin exploration activities in the Karoo, but project co-leader Professor Maarten de Wit believes fracking to test production is unlikely to start before 2018, giving a window of opportunity to gain new knowledge of the underground water and other natural systems in the Karoo, and to establish a forensic baseline.

The study also aims to determine how much gas there might be, how much can potentially be extracted, how the exploitation of gas will affect natural resources and eco-system services, and whether or not there will be positive socio-economic consequences.

As the project is not yet complete, no published reports or papers are currently available.

6.4 The USA

6.4.1 Background

The production of natural gas from deep shale deposits in the USA by way of horizontal drilling and UGEE processes has experienced a significant boom in recent years. Shale gas accounted for only 1.6% of total US natural gas production in 2000, but this percentage had increased to 4.1% by 2005 and to 23.1% by 2010 (Wang and Krupnick, 2013). However, there are also increasing concerns about the potential environmental consequences of shale gas production, including air pollution (Richardson *et al.*, 2013).

Shale formations across the USA have been developed to produce natural gas in small, but continuous, volumes since the earliest years of commercial natural gas production. The majority of these early efforts to produce gas from shale formations did not differ markedly from the drilling and completion methods applied to conventional reservoir rocks: they used vertical wells coupled with relatively small stimulations. However, during the 1980s, the Mitchell Energy and Development Corporation began attempts to develop the Barnett Shale in the area around Fort Worth, Texas. Throughout the mid-1990s, this company experimented with hydraulic fracturing techniques and, to a more limited degree, horizontal drilling in the Barnett Shale. This combination of sequenced hydraulic fracture treatments and horizontal wellbores facilitated the expansion of shale gas development. After the successful application of these two technologies in the Barnett Shale, the development of shale gas resources in other basins grew rapidly from 2006 (NETL, 2013).

The regulation of shale gas development is complicated and evolving. The complexity largely stems from the multiple layers of government responsibility, the variation in regulatory approaches across states and mineral rights ownership issues. In addition, the speed of shale gas development has left some state legislatures and regulators, particularly in states in which this level of oil and gas activity is unprecedented in modern times (e.g. Pennsylvania and New York), playing a game of “catch up” (NETL Strategic Center for Natural Gas and Oil, 2013).

Activities are regulated under federal, state and local regulations. All of the laws, regulations, and permits that apply to conventional oil and gas exploration and production activities apply equally to shale gas and shale oil activities. The USEPA administers most of the federal laws, although development on federally owned land is managed primarily by the Bureau of Land Management (BLM), which is part of the

Department of the Interior, and the US Forest Service, which is part of the Department of Agriculture (NETL Strategic Center for Natural Gas and Oil, 2013).

In addition, each state in which oil and gas is produced has one or more regulatory agencies that handle well permits (including their design, location, spacing, operation and abandonment) and regulate activities with potential environmental impacts (including water withdrawals and disposal, waste management and disposal, air emissions, underground injection, wildlife impacts, surface disturbances, and worker health and safety) (NETL Strategic Center for Natural Gas and Oil, 2013).

In some cases, municipalities also have an important role, and can place additional constraints on well pad locations, drilling and fracking techniques, and waste disposal methods (Richardson *et al.*, 2013).

The specific characterisation of the baseline air quality environment prior to initiating UGEE activities is not typically addressed in the guidance and legislation covering the management of air quality. With respect to air quality, the regulatory strategies focus on:

- reduced-emission (“green”) well completions;
- requirements for vapour recovery units on tanks;
- requirements for low-emission production facilities and associated piping;
- venting restrictions (venting is banned in six states, and restricted in 11 (Richardson *et al.*, 2013));
- flaring restrictions (flaring is controlled in 20 states (Richardson *et al.*, 2013)).

For example, the first economically productive wells were drilled into the Marcellus Formation in Pennsylvania in 2005. Since then, thousands of Marcellus wells have been drilled across Pennsylvania, northern West Virginia and eastern Ohio. In August 2013, the Pennsylvania Department of Environmental Protection (DEP) revised its technical guidance with respect to the air quality permitting criteria that should be applied to UGEE activities. The specific controls and practices applicable to these facilities, under the revised guidance, focus on operational processes. Some of these controls and practices are outlined below:

- In the first 60 days after a well has been put into production, and annually thereafter, a leak detection and repair programme must be implemented for the entire well pad and facility, including valves, flanges, connectors, storage vessels/tanks and compressor seals.
- Leaks should be repaired within 15 days of detection, unless the site is down or replacement parts have to be ordered. Repairs must also meet further criteria, as specified in the technical guidance.
- The aggregated emissions of VOCs from all facility sources must be less than 2.7 tons (which equates to approximately 2.5 metric tonnes) on a 12-month rolling basis.
- The emissions of hazardous air pollutants (HAPs) must be less than 1000 pounds (which equates to 454 kg) of a single HAP or 1 ton (approximately 0.91 tonnes) of all combined HAPs in any consecutive 12-month period.
- The combined NO_x emissions from the stationary internal combustion engines, wells and wellheads must be less than 100 pounds (45 kg) per hour, 0.5 ton (0.45 tonnes) per day, 2.75 tons (3.5 tonnes) per O_3 season and 6.6 tons (6.0 tonnes) per year on a 12-month rolling basis (but should not include emissions from sources operating under previously approved plans/operating permits).
- Flaring should be used only as provided in the technical guidance, primarily as a short-term or emergency activity. Any permanent flaring operations (e.g. as an emission control on storage vessels) must be enclosed.

However, if an unconventional well does not meet all of the above criteria, owners/operators of covered sources may still submit, to DEP, a request for determination seeking plan approval exemption.

Across the USA, operational air emissions and associated air quality are the main targets of monitoring and mitigation; while it has been recognised that characterisation of the air quality environment prior to commencing UGEE activities would be of benefit, activities are typically advanced to a stage at which this is no longer feasible.

However, with respect to air quality assessment, the work being carried out in Garfield County, Colorado, is notable. Colorado State University is currently carrying out a characterisation study of the air emissions from natural gas drilling and well completion operations in Garfield County. This study will further build on the air quality baseline characterisation study carried out as part of the Battlement Mesa Health Impact Assessment in Garfield County (Colorado School of Public Health, 2011).

The objectives of this study included:

- the monitoring of the levels of air pollutants throughout the well development and production process;
- the assessment of HAPs emitted from drilling activities and their impact on human health;
- the determination of physical and mental health trends over time in order to identify the health effects of drilling activities in Battlement Mesa;
- the tracking of ongoing community health status and the identification of community effects of drilling activities.

To meet these objectives and characterise baseline air quality, the following air quality monitoring was carried out for 1 year prior to the commencement of activities:

- 24-hour integrated samples were collected for the analysis of PAHs every 12 days;
- real-time monitoring of aromatic VOCs, PM_{10}, $PM_{2.5}$, NO_x, and O_3;
- sampling for any additional air pollutants identified to be of concern in the characterisation study.

The study output resulted in recommendations for operational mitigation measures and air quality monitoring programmes during well completion, as opposed to any specific recommendations that address baseline characterisation or the assessment of air quality prior to the commencement of projects.

In addition, there is growing concern regarding the significance of cumulative emissions, and their associated impacts, from the growing network of well pads and associated activities. On 17 December 2014, New York Governor Andrew Cuomo's administration announced that the State of New York would ban hydraulic fracturing in response to conclusions presented in a report prepared by the New York State Department of Health (2014) and comments made by the Acting Health Commissioner and the New York State Department of Environmental Conservation (NYSDEC) Commissioner. In addition, 24 US municipalities currently have bans in place (Koch, 2014).

6.5 Canada

Natural gas plays an important role in the Canadian economy, as it meets over 30% of Canada's energy needs and represents a large source of export revenue (Statistics Canada, 2012). In recent years, escalating gas prices and improved extraction technology have resulted in increased production from unconventional reserves, that is, tight gas (gas in low-permeability rock), coal-bed methane (gas associated with coal seams) and shale gas (CCA, 2014).

Alberta is the most mature development area in Canada with almost 400,000 wells drilled as of 2012. The regulation of Alberta's energy development, and thus the mandate for shale gas development, is the responsibility of the Alberta Energy Regulator (AER; formerly the Energy Resources Conservation

Board), which provides guidelines for drilling, completing, producing and abandoning oil and gas wells in the province. The AER also regulates environmental issues, deep-well disposal, and all aspects of water management, land access (roadways and lease design) and product transportation associated with the oil and gas industry. The AER's regulations are also widely used as guidance by other regulatory bodies in Canada (e.g. Government of New Brunswick, 2013; CCA, 2014).

As with other jurisdictions, the existing guidance and regulation with respect to UGEE-specific air quality focuses on the operational phase, and addresses emission limits and emission inventories, particularly with respect to venting and flaring, and general compliance with the ambient air quality standards (Canada's National Ambient Air Quality Standards and the maximum ground-level concentrations as defined by the Air Quality Regulation under Canada's Clean Air Act).

New Brunswick's "Rules for Industry" document (Government of New Brunswick, 2013) discusses the specification of ambient air quality monitoring programmes (in the context of the operational phase) and acknowledges that any ambient air quality monitoring programme will depend on the potential for cumulative air quality impacts, including factors such as:

- the intensities and types of existing and proposed activities in a given area (e.g. trucking, and types of pumps or generators);
- the presence of other oil or natural gas operators;
- the presence of other industrial activities, etc.

This document further sets out that an ambient air quality monitoring programme may be required to include any or all of the following components:

- a compilation of calculated emissions showing total pollutant outputs in a given area;
- ground level impact modelling showing the potential impact on ambient air quality, including the potential levels of smog-forming chemicals such as O_3;
- the installation of real-time multi-parameter ambient monitoring stations;
- the collection of grab samples;
- odour monitoring;
- upset or occurrence monitoring if odours or other unusual events occur.

In the course of the recent review of environmental impacts of shale gas extraction across Canada by the CCA (2014), several important uncertainties with regard to the environmental implications of UGEE activities were set out. The information gaps (relating to air quality) that were highlighted included:

- the absence of important baseline information on environmental conditions in shale gas regions;
- the rate and volume of fugitive methane emissions.

In addition, in Quebec, the Bureau d'audiences publiques sur l'environnement (BAPE) reached no conclusion on the impact of shale gas development on ambient air quality in the province because of insufficient information on the location and level of activities associated with the development (BAPE, 2011a, b). The inquiry also recognised that baseline observations of air quality are lacking in areas in which development is ongoing or proposed. However, the inquiry commission recommended that the Ministère du Développement durable, de l'Environnement et des Parcs should establish the initial state of air quality in the regions in which exploration and extraction activities are likely to take place. While the inquiry commission recognised that contaminant dispersion models would be required to understand the impact of the air emissions associated with the industry, it did not make any specific recommendations with respect to the baseline characterisation requirements, nor did it recommend the inclusion of any specific pollutants for monitoring.

6.6 Summary of Requirements and Experience

A full baseline characterisation of air quality has not been carried out prior to the commencement of commercial UGEE operations in all assessed jurisdictions in which such operations are ongoing. In many cases, this lack of baseline characterisation prior to the commencement of UGEE activities has been highlighted as an important information gap. As described in section 4.2.3, published studies suggest that air quality impacts may vary from being significantly detrimental (Katzenstein *et al*., 2003; Gilman *et al*., 2013; USEPA, 2015; Werner *et al*., 2015) to having little or no significance (Zielinska *et al*., 2011; Pacsi *et al*., 2013; Pennsylvania Department of Environmental Protection, 2013; Bunch et al., 2014); therefore, no clear consensus with respect to the range of pollutants that should be monitored has emerged. However, extensive studies into air quality and other environmental impacts are now being carried out across almost all jurisdictions.

Baseline characterisation activities, before operation commencement, began in the Karoo in South Africa in mid-2014, as part of a 3-year research programme. However, this work is not yet complete; therefore, there are not yet any published results.

Current recommendations in Germany also advise that a comprehensive initial state report be undertaken prior to any new UGEE operations. However, no guidance on monitoring programme specifics were published.

Recommendations for baseline studies and extensive investigations into potential air quality impacts have been made by many studies across all jurisdictions. As a result, Ireland is well placed to comply with such international recommendations and undertake baseline studies and thoroughly assess the potential impacts before UGEE operations, exploratory or otherwise, are carried out.

7 Conclusions

7.1 Introduction

While an extensive ambient air monitoring network is in operation across the island of Ireland, it is recognised that additional monitoring to support baseline characterisation would be beneficial for impact assessment on a project-by-project basis. In particular, there are no air monitoring stations within the two study areas shown in Figure 1.1. This section identifies and proposes a programme for air baseline monitoring (in terms of frequency, locations and the types of pollutants covered) that would be beneficial for an EIS.

7.2 Overarching Monitoring Requirements

Carrying out monitoring as described will serve two key purposes:

- to provide baseline information in order to support the EIA of proposed activities;
- to provide sufficient background information for any modelling of the potential impacts of any proposed UGEE activities.

In general, the ultimate purpose of monitoring is not merely to collect data, but also to provide scientists, policymakers and planners with the information required to make informed decisions about managing and improving the environment. Monitoring fulfils a central role in the decision-making process, by providing the necessary sound scientific basis for setting objectives, assessing compliance with targets and supporting planning decisions (WHO, 1999).

The following are important characteristics of any monitoring programme, in order to ensure that optimal use is made of the data collected:

- valid, agency-approved, measurement techniques or methods;
- pollutant measurement durations and averaging periods defined by relevant standards;
- the simultaneous collection of meteorological data (weather station);
- measurement accuracy and precision;
- adaptable to metrology standards;
- temporal completeness (data capture);
- spatial distribution, representativity and coverage with respect to the siting of monitors and weather stations;
- consistency from site to site and with the national network;
- international comparability and harmonisation.

Quality control is also key in the execution of any monitoring programme, in order to provide a robust dataset. Quality assurance goals should cover:

- the evaluation and selection of equipment;
- the control of routine site operations;
- the maintenance of a quality assurance/quality control monitoring plan;
- the establishment of a chain of calibration and traceability;
- the auditing and intercalibration of the network;

- the maintenance and support of systems;
- the maintenance of a critical spare parts inventory for system redundancy;
- the reviewing and managing of data.

7.3 General Monitoring Requirements

The overall monitoring objectives usually determine the target areas for the study, the priority pollutants and the number of sites or monitors required. The following factors should be considered when designing a monitoring programme:

- the major sources or emissions of pollutants in the area;
- the target receptors and environments;
- the weather and topography;
- model simulations of dispersion patterns in the area;
- existing air quality information (e.g. from screening studies);
- data on demography, health and land use.

In addition, certain practical considerations also apply to the selection of monitoring sites. For example, they must be accessible for site visits, but have adequate security to minimise the potential for public interference or vandalism. The monitors should be adequately housed to prevent them from being exposed to harsh weather conditions, and be located in areas without physical obstructions, such as nearby vegetation or terrain that could negatively impact measurements. Electricity must also be available for pollutant analysers and station infrastructure, and the location must facilitate automatic reporting if the station is to automatically transmit monitoring results.

Before the commencement of UGEE activities, monitoring should be performed to characterise the existing baseline environment and therefore allow a project EIA. To this end, it is proposed that the following guidelines be followed:

- The baseline air monitoring and associated environmental assessment should be performed before the commencement of any site activities.
- The type (parameter) and number of air monitors required to establish baseline pollutant concentrations should be determined. For a specific site with no existing air emissions sources or sources located nearby, one strategically positioned monitoring location may be adequate.
- An onsite meteorological station should be installed, or a representative, nearby meteorological station should be identified, to measure parameters such as wind speed, wind direction, barometric pressure and temperature. The wind speed and wind direction are measured simultaneously with pollutant measurements to help in the interpretation of the background data and help identify existing sources upwind of the site that may be contributing to baseline concentrations.
- Air monitoring should be conducted for a duration that is adequate for the collection of a representative dataset and that will allow a meaningful comparison with standards and legislation. Background monitoring should be carried out for no less than 1 year, and the need for continuous or intermittent hourly, daily or seasonal monitoring should be determined so that data can be compared with the appropriate standards. Further details are described in the following sections.

In order to ensure that the monitored data are of satisfactory quality, monitoring should be carried out in line with the relevant principles set out in the Air Quality Standards Regulations 2011 (S.I. No. 180/2011). In particular, the monitoring should be carried out in accordance with:

- Schedule 1, Part A, “Data quality objectives”;
- Schedule 3 “Assessment of ambient air quality and location of sampling points for the measurement of sulfur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter (PM10 and PM2.5), lead, benzene and carbon monoxide in ambient air”:
    - Part A (General);
    - Part B (Macroscale siting of sampling points);
    - Part C (Microscale siting of sampling points).

7.4 The Purpose of Site-Specific Baseline Air Monitoring

Before UGEE activities begin, target air pollutant levels at or in close proximity to the proposed UGEE site should be established. The purpose of establishing the baseline pollutant concentrations is to:

1. measure target pollutant concentrations at a specific location before any UGEE activities occur, supplement or update existing pollutant concentrations, or establish the existing local baseline concentrations in areas in which measurements are absent because a representative network does not exist or data from an existing national monitoring network are not representative;
2. provide baseline information to support the thorough environmental assessment of potential impacts;
3. provide sufficient background information to support the modelling of potential impacts of any proposed UGEE activities;
4. allow a distinction to be made between emissions from future UGEE site activities and emissions in the airshed[6] contributed by local and regional sources.

These baseline pollutant concentrations could, in principle, be determined from an existing monitoring network/monitoring site that adequately represents the air quality of the area, including the site of the proposed UGEE activities (if appropriate data exist). This approach, however, would require agency approval and potentially some degree of shorter term monitoring to confirm the suitability of the existing monitoring station data.

7.5 Baseline Air Monitoring Locations

The area in which a well is drilled is referred to as the well pad. (A typical test well pad would be approximately 7000 m^2 in size and provide enough space for the drilling rig equipment, piping and storage, and other site facilities, such as portable offices and worker toilet facilities. A test well pad of this size would, typically, support up to 10 wells spaced out across the site area.)

There is currently no information with regard to the likely distance between any proposed well pads or their potential distribution and, consequently, whether or not background measurements taken at one proposed site would be representative of background measurements at a second site. It is, therefore, recommended that monitoring sites be located at each proposed well pad or at a location representative of a discrete group of well pads.

If the proposed well field is well defined in advance, and the future locations of well pads in the area are relatively certain, a monitoring station strategically placed in a location that captures the mesoscale airshed, encompassing the well field, could serve as the representative background station for multiple future well locations.

6 An airshed is a part of the atmosphere that behaves in a coherent way with respect to the dispersion of emissions, or shares a common flow of air.

If it is proposed to use the concentrations measured at one well pad as representative of another, it should be the responsibility of the project proponent to prove, to the satisfaction of the relevant authorities, that this is indeed the case. Short-term monitoring may be required to support such cases.

In cases in which ambient pollutant concentrations are largely caused by mobile sources (NO_2, NO_x, PM_{10}, $PM_{2.5}$), the onsite monitoring may need to be supplemented by monitoring in the vicinity of the likely route networks, as described in the following sections, in order to support the determination of potential impacts related to the increased movement of HGVs.

7.6 Baseline Air Monitoring Equipment

It is not the intention of this report to be prescriptive in terms of the specifications of air monitoring equipment, and requirements for individual monitor manufacturers, models or measurement principles are not set out. However, equipment selection should be guided by requirements related to the following:

- meaningful comparisons with the averaging periods defined in the ambient standards (hourly, daily, etc.);
- meaningful comparisons with threshold values in terms of detection limits and the accuracy of monitoring equipment (e.g. the limit of detection should be below the relevant standards);
- meaningful comparisons with the existing ambient air monitoring network.

7.7 Pollutant Details

7.7.1 Rationale for recommendations

Section 4.2 describes the emissions to ambient air that could be associated with the UGEE process. Published studies report varying impacts on air quality, from significantly detrimental (Katzenstein *et al*., 2003; Gilman *et al*., 2013; USEPA, 2015; Werner *et al.*, 2015) to having little or no impact (Zielinska *et al*., 2011; Pacsi *et al*., 2013; Pennsylvania Department of Environmental Protection, 2013; Bunch *et al*., 2014); therefore, no clear consensus has been reached with regard to which compounds should form the critical elements of a monitoring programme or, indeed, if any should be excluded.

However, while UGEE processes have been linked to a wide range of emissions, there seems to be broad agreement in the available literature (including Groundwater Protection Council, 2009; Colorado School of Public Health, 2011; Walther, 2011; McKenzie *et al*., 2012; AMEC, 2013; NETL, 2013; Public Health England, 2013; Adgate *et al*., 2014; Maryland Department of the Environment Maryland Department of Natural Resources, 2014; Moore *et al*., 2014; Werner *et al*., 2015) with regard to the compounds or families of compounds that are most likely to be emitted during the process, even if estimations of the quantity of these emissions vary or are not yet well defined (Research Triangle Environmental Health Collaborative, 2013).

Studies of air quality around fracturing wells indicate the presence of chemical contaminants (Wolf Eagle Environmental, 2009; Colborn *et al*., 2011). Atherton *et al*. (2014) stated that while many contaminants in the air have potential to cause harm to human health, a number of issues should be noted. Firstly, although the amounts of contaminants in the air may be within safety standard limits, these standards are often based on the single-dose exposure of an adult, rather than on the chronic, long-term exposure of people who work or live around natural gas installations (Colborn *et al*., 2014). There may also be sub-groups of the population (e.g. children or pregnant women) who have increased susceptibility to environmental toxins by virtue of their physiological and immunological states (Lauver, 2012). In addition, Werner *et al.* (2014) reported that very few, if any, methodologically rigorous studies have examined the potential cause-and-effect relationship of UGEE activities and actual health outcomes in hazard analyses, in terms of exposure pathways and the health outcomes related to air emissions. Overall, adverse health impacts have often been attributed to these activities as a precaution. The available evidence, or lack thereof, is not sufficient to rule in or rule out significant or specific, future, or cumulative health impacts of UGEE activities.

Therefore the precautionary approach must underpin the recommendation of compounds for monitoring in the establishment of a baseline; the selection of compounds for supplementary monitoring has been determined based on established links with UGEE activities and *potential* impacts. The duration of monitoring and the temporal resolution of the data should allow meaningful comparisons with the relevant standards and support impact estimation. Based on the compounds and families of compounds agreed to be associated with UGEE activities in the available literature (discussed in more detail in section 4.2), and *independently* of whether or not significant impacts on human health or the environment have been established, the following pollutants are addressed in the recommendations contained in this report:

- NO_X and NO_2;
- SO_2;
- CO;
- O_3;
- PM (PM_{10} and $PM_{2.5}$);
- benzene and NMVOCs
- BaP and PAHs;
- NORM;
- methane.

A risk assessment approach was applied to the consideration of the primary air pollutants listed above. Those pollutants not regarded as resulting from UGEE activities have not been considered in detail in this study, including pollutants for which ambient air quality standards have been established in the CAFE Directive or Fourth Daughter Directive. Furthermore, it should also be borne in mind that because scientific knowledge and UGEE techniques are rapidly developing, any environmental assessment should take account of the latest knowledge available and the current state of related scientific research.

7.7.2 Nitrogen oxides and nitrogen dioxide

As discussed in Chapter 3, emissions of NO_x are generated primarily from fuel combustion processes and have been linked to UGEE activities through onsite activities, including increases in HGV movements associated with the operations. NO_2 is also a precursor for a number of harmful secondary air pollutants (as are other NO_x species), including nitric acid, the nitrate part of secondary inorganic aerosols and O_3 (WHO, 2013). The situation is also complicated by the fact that photochemical reactions take some time (depending on the composition of the atmosphere and various meteorological parameters), and air can travel a substantial distance before secondary pollutants are generated.

The WHO recommends that the following criteria are taken into account when designing a monitoring programme incorporating NO_2 (WHO, 2009):

- the concentrations are largely determined by road traffic emissions;
- the concentrations are typically highest in city centres and near roads.

Any monitoring programme should therefore be designed to also facilitate the assessment of traffic-related emissions, and to account for the fact that roadside concentrations are unlikely to be representative of ambient concentrations further from roads and vice versa.

Proposed site monitoring

Chronic (long-term) and acute (short-term) exposure to elevated NO_2 concentrations can result in impacts on human health; chronic exposure to elevated concentrations can also negatively impact on vegetation. As a result, the temporal resolution and the duration of the monitoring should allow the characterisation of the short-term peak and long-term average concentrations. For the purposes of the assessment of potential impacts, it is also necessary to be able to compare predicted concentrations with the ambient standards, which are expressed in both hourly and annual averages. This will allow useful comparison with the standards, set under the CAFE Directive, in any project environmental assessment. Therefore, monitoring should be performed at a temporal resolution that allows the determination of hourly averages, and be conducted for no less than 1 year.

The potential impacts of NO_x relate to long-term exposure, and, as a result, the limits are defined in terms of annual mean concentrations. The monitoring of annual average concentrations is, therefore, recommended.

Roadside concentrations

However, as ambient NO_2 levels largely result from mobile source emissions, background concentrations at a site or sites representative of background concentrations along the proposed route corridors should also be monitored, in order to allow the determination of the potential impacts of increased HGV movement.

In the absence of existing representative data, monitoring should ideally be carried out for a period of 6 months, including in both summer and winter periods. However, for practical reasons, the monitoring period may, if necessary, be shorter, but should preferably be at least 3 months and not less than 1 month, in compliance with National Roads Authority (NRA) guidelines for assessing the impact of national road schemes (NRA, 2011).

In Northern Ireland, the existing modelled background concentrations of NO_x and NO_2 may be used for the estimation of traffic-related impacts, as described in the *Design Manual for Roads and Bridges* (Highways Agency, 2009).

7.7.3 Sulfur dioxide

While SO_2 is not typically regarded as a critical compound in terms of UGEE-related emissions, particularly if flaring is routinely provided, on the basis of the precautionary principle, it is recommended that it is considered in any impact assessment. Monitoring should be carried out for no less than 1 month for the purposes of assessing local baseline conditions and whether or not the national air monitoring network is representative of average conditions.

7.7.4 Carbon monoxide

CO is not regarded as a critical compound in terms of UGEE-related emissions. The levels of CO at all stations across the island of Ireland are well within defined limits and have been for many years (DOENI, 2014; EPA, 2014). In addition, CO levels in the island of Ireland are expected to remain relatively low for the foreseeable future (EPA, 2014).

No supplementary baseline monitoring is recommended because of:

- the reported lack of significant CO emissions associated with UGEE operations;
- the consistently low levels of CO across the island of Ireland;
- expectations that CO will remain low for many years;

For the purposes of project EIAs, the existing national air monitoring network is deemed to provide sufficient data for assessment of potential impacts. Moreover, the use of existing monitoring results carried out in Zone C of Ireland (23 large towns in Ireland with a population of > 15,000) will effectively act as a conservative estimate with respect to rural background levels.

7.7.5 Ozone

As described in section 5.4.4, O_3 is not directly released through UGEE processes; instead, Irish O_3 levels are highly influenced by transboundary sources. In addition, ambient O_3 levels are not consistent with changes in emission levels of O_3 precursors on a regional scale. Instead, a reduction of O_3 levels will require a European, and possibly a global, effort to reduce emissions of O_3 precursors.

No supplementary baseline monitoring is recommended as:

- Baseline surface O_3 levels in Europe are changing with time and are not consistent with changes in emission levels of O_3 precursors on a regional scale (Tripathi *et al*., 2010). Therefore, EIAs of any proposed UGEE developments should address emissions of O_3 precursors as opposed to O_3 itself, both with regard to direct impacts and the potential cumulative influence on transboundary O_3 trends, as opposed to any potential influence on local O_3 levels.
- Data from Mace Head, Ireland, are extensively analysed and used to characterise background levels of O_3 (Tripathi *et al*., 2012).

7.7.6 Particulate matter (PM_{10} and $PM_{2.5}$)

As discussed in Chapter 3, emissions of PM have been linked to UGEE activities, as a result of onsite activities and the increase in HGV movement associated with the operations.

Proposed site monitoring

Background measurements of PM_{10} and $PM_{2.5}$ should be taken at the well pad for no less than 1 year to characterise onsite background concentrations. The temporal resolution of the monitoring should allow daily and annual averages to be calculated.

Roadside concentrations

However, as PM levels are also influenced by road emissions, background concentrations at a site or sites representative of background concentrations along the proposed route corridors should be monitored as described below.

In the absence of existing representative data, monitoring should be in compliance with NRA guidelines for assessing the impact of national road schemes (NRA, 2011), and, ideally, should be carried out for a period of 6 months, including in both summer and winter periods. However, for practical reasons, the monitoring period may, if necessary, be reduced to 3 months, but must not be reduced to less than 1 month. If data from short-term monitoring campaigns are used, the results may be adjusted to an equivalent annual mean concentration by comparison with fixed monitoring stations (NRA, 2011).

In Northern Ireland, modelled background concentrations of PM may be used in the estimation of traffic-related impacts.

7.7.7 Benzene and non-methane volatile organic compounds

UGEE processes can result in emissions of benzene and a range of VOCs. As described in Chapter 3 and section 4.8, benzene and VOCs can have significant negative impacts on human health.

Limit values for benzene are defined by the CAFE Directive on the basis of the impacts on health and vegetation, with averaging periods of 1 hour and 1 calendar year. Therefore, in order to provide meaningful data, background monitoring of benzene should be undertaken for no less than 1 year at the well pad, and at a temporal resolution of no more than 1 hour.

The background monitoring of hourly VOC levels should also be undertaken for no less than 1 year at the well pad. Typically, VOCs are separated by gas chromatography and measured by a mass spectrometer or using multi-detector techniques, and the concentrations of the individual VOCs are determined from the magnitude of the resultant peaks. While the monitoring of the concentration of individual VOCs is dependent on peak resolution and identification, the following targets should be considered for monitoring as part of a NMVOC monitoring programme (Texas Commission on Environmental Quality, 2009; Zielinska *et al.*, 2011; McKenzie *et al.*, 2012):

- ethane
- ethylene
- acetylene
- propane
- propylene
- dichlorodifluoromethane
- methyl chloride
- isobutane
- vinyl chloride
- 1-butene
- 1,3-butadiene
- *n*-butane
- trans-2-butene
- bromomethane
- cis-2-butene
- 3-methyl-1-butene
- isopentane
- trichlorofluoromethane
- 1-pentene
- *n*-pentane
- isoprene
- trans-2-pentene
- 1,1-dichloroethylene
- cis-2-pentene
- methylene chloride
- 2-methyl-2-butene
- 2,2-dimethylbutane
- cyclopentene
- 4-methyl-1-pentene
- 1,1-dichloroethane
- cyclopentane
- 2,3-dimethylbutane
- 2-methylpentane
- 3-methylpentane
- 2-methyl-1-pentene + 1-hexene
- *n*-hexane
- chloroform
- trans-2-hexene
- cis-2-hexene
- 1,2-dichloroethane
- methylcyclopentane
- 2,4-dimethylpentane
- 1,1,1-trichloroethane
- carbon tetrachloride
- cyclohexane
- 2-methylhexane
- 2,3-dimethylpentane
- 3-methylhexane
- 1,2-dichloropropane
- trichloroethylene
- 2,2,4-trimethylpentane
- 2-chloropentane
- *n*-heptane
- cis-1,3-dichloropropylene
- methylcyclohexane
- trans-1,3-dichloropropylene
- 1,1,2-trichloroethane
- 2,3,4-trimethylpentane
- toluene
- 2-methylheptane
- 3-methylheptane
- 1,2-dibromoethane

- *n*-octane
- tetrachloroethylene
- chlorobenzene
- ethylbenzene
- *m*- and *p*-xylene
- styrene
- 1,1,2,2-tetrachloroethane
- *o*-xylene
- *n*-nonane
- isopropylbenzene
- *n*-propylbenzene
- *m*-ethyltoluene
- *p*-ethyltoluene
- 1,3,5-trimethylbenzene
- *o*-ethyltoluene
- 1,2,4-trimethylbenzene
- *n*-decane
- 1,2,3-trimethylbenzene.
- *m*-diethylbenzene
- *p*-diethylbenzene
- *n*-undecane
- carbonyl sulfide
- hydrogen sulfide
- methyl mercaptan
- ethyl mercaptan
- thiophene
- dimethyl sulfide
- isopropyl mercaptan
- trans-butyl mercaptan
- isobutyl mercaptan
- butyl mercaptan
- 3-methyl thiophene
- methyl ethyl sulfide + *n*-propyl
- mercaptan
- dimethyl disulfide
- 2-ethyl thiophene + 2,5-dimethyl
- thiophene
- diethyl sulfide
- tetrahydrothiophene
- diethyl disulfide
- formalydehyde

Although formaldehyde is included in the above list, it should be noted that, in the natural environment, formaldehyde is an intermediary in the methane cycle with a short half-life and low background concentrations (WHO, 2001). The major anthropogenic sources of formaldehyde that affect humans are indoors (WHO, 2001). Levels of formaldehyde are not readily monitored using gas chromatography, so consideration should be given to supplementary formaldehyde-specific monitoring in order to confirm the expected low background levels.

7.7.8 Benzo[a]pyrene and polycyclic aromatic hydrocarbons

As described in Chapter 3 and section 4.9, UGEE processes are associated with elevated levels of PAHs, which can have significant impacts on human health. Typically BaP is used as a marker for all PAHs, and annual average target values are defined under the CAFE directive. Therefore, concentrations of BaP should be measured within the curtilage of the proposed well pad for a period of no less than 1 year. No temporal resolution for the monitoring is specified.

7.7.9 Radon

UGEE processes may result in emissions of radon, particularly at the wellhead and its vicinity, and during the flowback and production periods. Outdoors, radon quickly dilutes to harmless levels (RPII, 2014). However, when it enters a building (typically from the ground through cracks and pores in foundations), it can sometimes accumulate to unacceptably high levels, and elevated radon levels can result in health impacts, such as lung cancer. Therefore, it is recommended that background levels of radon are measured regularly within the curtilage of the proposed well pad over a 1 year period. This will facilitate the characterisation of the radon levels released during the UGEE process. No temporal resolution is specified, and sampling may be carried out intermittently at regular intervals.

In addition, indoor radon concentrations should be measured at a selection of representative residential receptors in the vicinity of the proposed works. Measurements should be carried out for at least 3 months to allow for day-to-day variations in radon levels, and to allow comparison with the national reference level.

7.7.10 Methane

At low levels, methane is non-toxic and does not pose a health threat. At very high levels and in enclosed spaces, methane can displace the oxygen in the air and cause asphyxiation (suffocation) and symptoms such as headaches, dizziness, weakness and nausea. Such high levels would not occur in ambient air because of the dispersion of the methane. However, methane can be involved in the formation of ground-level O_3.

Nonetheless, fugitive emissions of methane are of significant importance in the context of climate change, and also have other implications for public health.

No standards for ambient levels of methane are currently specified. As a result, it is advised that background concentrations of methane be characterised in order to allow life cycle emission calculations and leakage monitoring. To this end, ambient levels of methane should be measured for a period of no less than 1 month. The temporal resolution of measured concentrations should be defined by the monitoring method and equipment.

Although background methane concentrations are known to fluctuate seasonally, monitoring for 1 month will allow meaningful comparisons and extrapolations based on long-term methane studies at Mace Head, Galway, by the Earth System Research Laboratory, Global Monitoring Division.

7.8 Conclusions

This report addresses the following three areas:

- existing air monitoring data, including data on NORM;
- the requirements and experience of air baseline characterisation in countries in which UGEE projects/operations have taken or are taking place;
- the identification and recommendation of guidelines on the extent of the air baseline monitoring (in terms of frequency, locations and the types of pollutants covered) that should be carried out for an EIS (i.e. on a project basis).

While Ireland has an extensive air quality monitoring network designed chiefly to comply with EU ambient monitoring requirements, it was found that existing data will need to be supplemented with data from additional monitoring in order to allow comprehensive baseline characterisation.

A full baseline characterisation of air quality has not been carried out prior to the commencement of commercial UGEE operations in all assessed jurisdictions in which such operations are ongoing. In many cases, this lack of baseline characterisation before commencing UGEE activities has been highlighted as an important information gap. However, extensive studies into air quality and other environmental impacts are being carried out across almost all jurisdictions. Recommendations for baseline studies and extensive investigations into potential air quality impacts have been made as a result of many studies across all jurisdictions. As a result, Ireland is well placed to comply with international recommendations that baseline studies should be carried out, and the potential impacts should be thoroughly assessed before UGEE operations, exploratory or otherwise, are carried out.

Recommendations for additional ambient air quality monitoring are described for NO_x, PM, benzene and NMVOCs, BaP and radon, as summarised in Table 7.1.

Table 7.1. Recommendations for supplementary baseline ambient air quality monitoring

Pollutant	Monitoring location/locations	Duration of monitoring	Minimum temporal resolution
NO_2	Within the curtilage of the well pad	1 year[b]	Hourly
NO_2	Roadside background[a]	Not less than one month	Hourly
NO_x	Within the curtilage of the well pad	1 year[b]	Not specified
SO_2	Within the curtilage of the well pad	1 month	Hourly
CO	None specified	None specified	Not specified
O_3	None specified	None specified	Not specified
PM_{10}	Within the curtilage of the well pad	1 year[b]	Daily
PM_{10}	Roadside Background	Not less than one month	Daily
$PM_{2.5}$	Within the curtilage of the well pad	1 year[b]	Daily
$PM_{2.5}$	Roadside Background[a]	Not less than one month	Daily
Benzene and NMVOCs	Within the curtilage of the well pad	1 year[b]	Hourly
BaP	Within the curtilage of the well pad	1 year[b]	Not specified
Radon (outdoor)	Within the curtilage of the well pad	1 year[b]	At regular intervals to be defined by monitoring method or equipment
Radon (indoor)	Representative receptors in the vicinity of the proposed development	3 months	Not specified
Methane	Within the curtilage of the well pad	Not less than 1 month	To be defined by monitoring method or equipment

[a]In Northern Ireland, use may be made of the modelled background concentrations for the purposes of calculations of traffic-related impacts.

[b]It is acknowledged that in the case of NO_2, NO_x, PM_{10}, $PM_{2.5}$, benzene and NMVOCs, BaP and radon, the monitored data may indicate that background concentrations are consistent from month to month or that the existing network adequately represents ambient concentrations. In this case, it is recommended that the possibility of curtailing the monitoring period be addressed with the relevant agencies, the EPA or the NIEA.

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Abbreviations

AER	Alberta Energy Regulator
AOT_{40}	Accumulated O_3 over a threshold of 40 ppb; equal to the sum of the difference between hourly concentrations greater than 80 µg/m^3 (40 ppb) and 80 µg/m^3 over a given period using only the 1-hour values measured between 8:00 and 20:00 Central European Time each day
BaP	Benzo[*a*]pyrene
BAPE	Bureau d'audiences publiques sur l'environnement
BSS	British Standards Society
BTEX	Benzene, toluene, ethylbenzene and xylene
CAFE	Ambient Air Quality and Cleaner Air for Europe
CCA	Council of Canadian Academies
CO	Carbon monoxide
DCCAE	Department of Communications, Climate Action and Environment
DCELG	Department of Environment, Community and Local Government
DCENR	Department of Communications, Energy and Natural Resources
DECC	Department of Energy and Climate Change
DEFRA	Department for Environment, Food and Rural Affairs
DEP	Pennsylvania Department of Environmental Protection
DETI	Department of Enterprise, Trade and Investment
DfE	Department for the Economy
DMR	Department of Mineral Resources
EA	Environment Agency
EC	European Commission
EIA	Environmental impact assessment
EIS	Environmental impact statement
EPA	Environmental Protection Agency
EU	European Union
GSI	Geological Survey of Ireland
GSNI	Geological Survey of Northern Ireland
HAP	Hazardous air pollutant
HGV	Heavy goods vehicle
ICRP	International Commission on Radiological Protection
IPCC	Intergovernmental Panel on Climate Change
JRP	Joint Research Programme

LAQM	Local air quality management
NCB	Northwest Carboniferous Basin
NEC	National Emission Ceilings
NETL	National Energy Technology Laboratory
Northern Ireland AMN	Ambient Air Monitoring Network of Northern Ireland
NIEA	Northern Ireland Environment Agency
NMVOC	Non-methane volatile organic compound
NO_2	Nitrogen dioxide
NORM	Naturally occurring radioactive materials
NO_x	Oxides of nitrogen
NRA	National Roads Authority
O_3	Ozone
PAH	Polycyclic aromatic hydrocarbon
PGI	Polish Geological Institute
PM	Particulate matter
PM_{10}	Particulate matter with particles of diameters of 10 µm or less
$PM_{2.5}$	Particulate matter with particles of diameters of 2.5 µm or less
RECs	Reduced emissions completions
Ireland AMN	Ambient Air Monitoring Network of Ireland
RPD	Radiation Protection Division
RPII	Radiological Protection Institute of Ireland
SEA	Strategic environmental assessment
S.I.	Statutory Instrument
SO_2	Sulfur dioxide
UGEE	Unconventional gas exploration and extraction
UKOOG	United Kingdom Onshore Operators Group
USEPA	United States Environmental Protection Agency
VOC	Volatile organic compound
WHO	World Health Organization

Final Report 3: Baseline Characterisation of Air Quality

Roinn Cumarsáide, Gníomhaithe ar son na hAeráide & Comhshaoil
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Unconventional gas exploration and extraction (UGEE) involves hydraulic fracturing ("fracking") of low permeability rock to permit the extraction of natural gas on a commercial scale from unconventional sources, such as shale gas deposits, coal seams and tight sandstone.

The UGEE Joint Research Programme (JRP) (**www.ugeeresearch.ie**) is composed of five interlinked projects and involves field studies (baseline monitoring of water and seismicity), as well as an extensive desk-based literature review of UGEE practices and regulations worldwide. The UGEE JRP was designed to provide the scientific basis that will assist regulators - in both Northern Ireland and Ireland - to make informed decisions about whether or not it is environmentally safe to permit UGEE projects/operations involving fracking. As well as research in Ireland, the UGEE URP looks at and collates evidence from other countries.

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List of Outputs:

- Final Report 1: Baseline Characterisation of Groundwater, Surface Water and Aquatic Ecosystems
- Summary Report 1: Baseline Characterisation of Groundwater, Surface Water and Aquatic Ecosystems
- Final Report 2: Baseline Characterisation of Seismicity
- Summary Report 2: Baseline Characterisation of Seismicity
- Final Report 3: Baseline Characterisation of Air Quality
- Summary Report 3: Baseline Characterisation of Air Quality
- Final Report 4: Impacts & Mitigation Measures
- Summary Report 4: Impacts & Mitigation Measures
- Final Report 5: Regulatory Framework for Environmental Protection
- Summary Report 5: Regulatory Framework for Environmental Protection
- UGEE Joint Research Programme Integrated Synthesis Report

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