Report No.442

epa Research

Impact of Nitrogen Dioxide on Health with Particular Emphasis on Vulnerable Groups

Authors: Aonghus Ó Domhnaill, Margaret O'Mahony, Brian Broderick, Martina Hennessy, Aoife Donnelly, Owen Naughton, Eimir Hurley, Philip Carthy, Anne Nolan, Frank Moriarty and Seán Lyons

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Rialtas na hÉireann
Government of Ireland

Environmental Protection Agency

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

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

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

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

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

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

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

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Identifying pressures

Exposure to nitrogen dioxide (NO_2) is associated with adverse effects on hospital admissions for various diagnoses; respiratory illnesses such as asthma, cancer, adverse birth outcomes, as well as mortality. The main source of NO_2 in Ireland is from road transport, particularly diesel engines. Other sources include off-road machinery, industrial and construction activities, and electricity and heat production.

The project involved a number of analyses. In the first, associations between the model estimations of NO_2 and the health data of >8000 adults aged over 50 years (TILDA database) indicated that a 1ppb increase in NO_2 concentration was associated with a 0.24 percentage point increase in the probability of reporting an asthma diagnosis. In another analysis, using the HSE-PRCR prescribing database, the project found a positive association between respiratory item prescription rates and PM2.5 levels but the results for NO_2 were inconclusive. The project also developed an enhanced Wind Sector Land Use Regression (WS-LUR) model that can estimate ambient NO_2 concentrations at any location in Ireland with particular emphasis on vehicle fleet changes and traffic flow impacts on NO_2. The model was used to assess mitigation policies for the reduction of NO_2.

Informing policy

The results of the respiratory item prescribing rate analysis using the HSE-PCRS database demonstrated a strong positive association between PM2.5 and prescribing rates, particularly in young children. The results of the analysis of NO_2 levels on the health of older adults demonstrated a strong positive association with asthma prevalence. Policies seeking to improve air quality nationally, therefore, need to be intensified.

The mitigation strategy analyses showed how a range of possible traffic management and infrastructure measures could reduce overall NO_2 levels. Therefore, it is recommended that resources and policy development are targeted at developing incentives to reduce car use, promoting and adequately resourcing public transport and active transport modes.

Initial investigations as part of the project concluded that researcher access to available health datasets is extremely limited, reducing the potential to study the impacts of air pollution on health. It is recommended that policies and protocols be developed to enable researchers to access existing health data, without compromising privacy.

Developing solutions

As transport is the largest source of NO_2 in Ireland, a key focus of the project was to develop solutions for this sector. The analysis of the impact of Covid-19 demonstrated that significant reductions in some air pollutants were realised when a large proportion of the population worked from home. Homeworking has the potential to contribute significantly to improving air quality relating to NO_2.

A range of potential solutions were evaluated in the mitigation strategy analyses. They included relocating businesses away from highly polluted areas, replacing diesel with electric vehicles in the public service fleets, introducing a Low Emission Zone in Dublin and introducing a bypass/ring road around a city. All strategies lowered traffic levels in different contexts and thereby reduced modelled NO_2 levels. While some strategies may be more easily implemented than others, all offer significant potential to reduce air pollution.

EPA RESEARCH PROGRAMME 2021–2030

Impact of Nitrogen Dioxide on Health with Particular Emphasis on Vulnerable Groups

(2016-CCRP-MS-42)

EPA Research Report

Prepared for the Environmental Protection Agency

by

Trinity College Dublin

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ACKNOWLEDGEMENTS

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

The authors would like to acknowledge the members of the project steering committee, namely Barry Colleary (National Transport Authority), Martin Fitzpatrick (Dublin City Council), Aisling O'Connor (Environmental Protection Agency), John McEntagart (Environmental Protection Agency), Máirín Ní Cheallaigh (Department of Transport), Maurice Harnett (Department of Transport), Patrick Kenny (Environmental Protection Agency), Heather Walton (King's College London), Michael Young (Department of the Environment, Climate and Communications) and Anne Mason (Research Project Manager on behalf of the EPA).

This report is based on research carried out/data from 2016 to 2021. More recent data may have become available since the research was completed.

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

EPA RESEARCH PROGRAMME 2021–2030

Published by the Environmental Protection Agency, Ireland

ISBN: 978-1-80009-137-5

November 2023 Online version

Price: Free

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Executive Summary

Nitrogen dioxide (NO_2) is a highly reactive gas and is primarily produced by the burning of fuel. It forms from emissions from cars, trucks and buses and power plants. Exposure to NO_2 has been associated with adverse effects on hospital admissions for various diagnoses; decrements in measures of lung function; increases in respiratory symptoms, asthma incidence, adverse birth outcomes and mortality. In terms of outdoor ambient air quality, the main source of NO_2 in Ireland is road transport.

The objectives of the project were as follows:

1. Use currently available air pollution measurements, and recent research results on the influence of meteorological and source parameters (including transport vehicle characteristics and population mobility demands), to identify a set of characteristics for the locations in Ireland that are at most risk of experiencing high levels of NO_2.
2. Use the Health Service Executive Primary Care Reimbursement Service (HSE-PCRS) prescribing database to establish baseline data linking NO_2 levels with the prescription of drugs used to treat asthma and chronic obstructive airways disease.
3. Explore the Growing Up in Ireland (GUI) and the Irish Longitudinal Study on Ageing (TILDA) databases to investigate if relationships between the prevalence of respiratory symptoms in vulnerable groups and NO_2 levels exist, within database constraints (TILDA, 2018).
4. Review policies and strategies being implemented by other countries to bring NO_2 within compliance levels and identify a set of effective and efficient solutions to reduce and mitigate the impact of the transport sector on NO_2 levels in Ireland, given this sector's predominance in the output of NO_2 emissions (EPA, 2019).

To deliver on the project's objectives, a range of different models and methods were required. In the case of objectives 1 and 4, an existing land use regression model was enhanced to include data describing the national distribution of vehicle characteristics, including vehicle fleet breakdown, Euro classifications and fuel types.

To meet the requirements of objective 2, HSE-PCRS and NO_2 data were used to link NO_2 levels with the prescription of drugs used to treat asthma and chronic obstructive airways disease. Objective 3 involved the exploration of existing health databases to investigate if relationships between the prevalence of respiratory symptoms in vulnerable groups and NO_2 levels exist, within database constraints. Relevant data from the TILDA database were used with modelled levels of NO_2 to investigate the links between NO_2 and asthma prevalence.

The findings from the HSE-PCRS prescribing rate analysis suggest that, for most of the outcomes investigated, there was no association between the levels of NO_2 and the prescribing rates. Although the focus of the project was on NO_2, the team had the opportunity to consider particulate matter consisting of particles with diameter of 2.5 μm or less ($PM_{2.5}$), in addition to NO_2. $PM_{2.5}$ can cause serious health problems. In most regions, there was an association between $PM_{2.5}$ and the prescribing rate, taking account of the impact of winter on dispensing. This was most pronounced with oral steroids and especially in the subgroup analyses undertaken in the 0–4 years age group.

The results from the TILDA analysis suggest that a 1 part per billion (ppb) increase in NO_2 concentration is associated with a 0.24 percentage point increase in the probability of reporting an asthma diagnosis for those exposed to levels of $<$ 13.1 ppb. In addition, a 1 ppb increase in NO_2 concentration was associated with a 0.26 percentage point increase in the probability of requiring medication for asthma. The magnitude of association is large for both models.

The enhanced wind sector land use regression model was successfully employed to assess the impact of a number of mitigation strategies on NO_2 levels: (1) relocating businesses from a congested area with significant air pollution; (2) replacing diesel vehicles with electric vehicles in the public service vehicle fleet; (3) introducing a low-emission zone (LEZ) in Dublin; and (4) introducing a city bypass/ring road. In absolute concentration reduction terms, none of the investigated strategies was indicated as being more successful than the others, with maximum improvements in annual average NO_2 concentrations of approximately 2 μg/m^3 being predicted in each case. Greater reductions in concentration could be achieved by implementing multiple strategies together.

1 Introduction

Nitrogen oxides (NO_x) are formed by the combination of oxygen and nitrogen at high temperatures (WHO, 2010; Ó Domhnaill *et al*., 2023). Most nitrogen oxides are emitted as nitric oxide (NO), but in ambient conditions they are rapidly oxidised in air to form nitrogen dioxide (NO_2), which is considered a primary pollutant. In terms of outdoor ambient air quality, the main source of NO_2 in Ireland is road transport (EPA, 2019a), although other forms of transport and stationary sources also contribute to emissions. For road transport, diesel engines emit more NO_2 than petrol engines, and their popularity in recent years has been of some concern, especially in urban areas, where public exposure is highest (Ó Domhnaill *et al*., 2023). Other sources of NO_2 include off-road machinery, industrial and construction activities, and electricity and heat production (EPA, 2019a). Long-range transport pollution also makes a significant contribution to NO_2 concentrations in Ireland (ESA, 2020).

Exposure to NO_2 has been associated with adverse effects on hospital admissions for various diagnoses; decrements in measures of lung function and lung function growth; and increases in respiratory symptoms, asthma incidence, adverse birth outcomes and mortality (WHO Europe, 2013; US EPA, 2016; Ó Domhnaill *et al*., 2023). The evidence of associations of ambient concentrations of NO_2 with a range of effects on health has strengthened in recent years, and the associations are robust to adjustment for other pollutants, including some particle metrics (Ó Domhnaill *et al*., 2023).

1.1 Monitoring of Nitrogen Dioxide

The EPA, working with local authorities and other public bodies, has established 96 air pollution monitoring stations, 18 of which were installed in 2020 (EPA, 2021; Ó Domhnaill *et al*., 2023). The EPA is finalising the National Ambient Air Quality Monitoring Programme, which involves a greatly expanded national monitoring network providing enhanced real-time information to the public (EPA, 2017). Further monitoring at new locations will provide a clearer image of the standard of air quality in Ireland, confirm if Ireland complies with EU standards (EU, 2008) and World Health Organization (WHO) guidelines (WHO, 2005, 2021), and assist in highlighting potential problem locations in the country that may require mitigation plans to limit or reduce air pollution.

The expansion of the network as part of the programme is seen to be a positive approach for illustrating local air quality conditions to the public and encouraging people to think about improving air quality in their everyday decisions, such as on modes of transport or home heating. Information from the monitoring stations is transferred to an Air Quality Index for Health map (EPA, 2019b), which divides the country into regions of small towns and large towns, Cork City and Dublin County. The remaining area of the country, not covered by those regions, is split between the rural west and rural east regions, with an index rating assigned to each region. Real-time information from the monitoring stations is then used to categorise the air quality as good, fair, poor or very poor in each of the regions.

WHO guidelines (WHO, 2005) and the EU's Directive on ambient air quality and cleaner air for Europe (Directive 2008/50/EC) (EU, 2008) have set out short-term and long-term concentration limits for numerous air pollutants, including NO_2 (Ó Domhnaill *et al*., 2023). The short-term limit (1-hour mean) for NO_2 of 200 $\mu g/m^3$ was set after various animal and human studies concluded that concentrations in excess of this limit are considered toxic and have a significant impact on health (WHO, 2005). This limit was adopted by the EU directive, which requires that the concentration level should not exceed this value more than 18 times a year at any individual monitoring station (Ó Domhnaill *et al*., 2023). The long-term limit (annual mean) of 40 $\mu g/m^3$ was set based on results from studies carried out on mixtures of air pollutants containing NO_2 that showed that people experienced health effects with increasing NO_2 concentrations (WHO, 2005; Ó Domhnaill *et al*., 2023). In September 2021, as this project was drawing to a close, the WHO changed its guideline values for NO_2 to an annual mean of 10 μg/m^3 and a 24-hour mean of 25 μg/m^3 (WHO, 2021; Ó Domhnaill *et al*., 2023). The WHO made the changes because the adverse health effects of the exposure of the human population to air pollution have seen a marked increase (WHO, 2021). Much has been learned about global concentrations of pollutants such as NO_2 and the contribution of pollutants to the global burden of disease in the 15 years since the previous guidelines were published (WHO, 2021; Ó Domhnaill *et al*., 2023). The aim of the new guidelines is to help reduce levels of air pollution to decrease the enormous health burden resulting from air pollution throughout the world (WHO, 2021). At the time of writing, it should be noted that EU air pollutant level limits do not yet include consideration of the revised WHO limits, but that work to align EU air quality standards more closely with the new WHO limits is ongoing as part of the revision of the EU's Ambient Air Quality Directive.

In accordance with EU Directive 2008/50/EC, an alert threshold exists where members of the public must be notified if concentration levels of NO_2 exceed 400 μg/m^3 for more than 3 consecutive hours. The EU directive also sets out thresholds for both the annual mean and hourly concentrations to protect human health (EU, 2008). The upper assessment threshold for the hourly limit is set at 70% (140 μg/m^3) of the limit concentration and the lower assessment threshold is set at 50% (100 μg/m^3). The annual mean upper and lower assessment thresholds are set at 80% (32 μg/m^3) and 65% (26 μg/m^3), respectively.

Between 2000 and 2010, the annual mean limit value was exceeded on four occasions in Ireland, all at Dublin City monitoring stations. In response to the exceedance in 2009, all of the Dublin County Councils (Dublin City, South Dublin, Fingal County and Dún Laoghaire Rathdown County) cooperated to develop an Air Quality Management Plan to tackle the issue of increasing air pollution in the county (Dublin City Council, 2009; Ó Domhnaill *et al*., 2023) and the report *Smarter Travel Policy: A Sustainable Transport Future* was published to identify objectives for reducing transport-related air pollution in Ireland from 2009 to 2020 (Department of Transport, 2009). In 2019, the annual mean limit of 40 μg/m^3 was exceeded at a new monitoring site located at St John's Road in Dublin, which required the preparation of an Air Quality Management Plan by the above local authorities.

The lower assessment threshold of 100 μg/m^3 has been breached more than 18 times in multiple years since 2010 at both the Winetavern Street and Blanchardstown monitoring stations. The EU hourly guideline has not been exceeded at any location since its implementation in 2010, but records show that in 2001 concentrations of 200 μg/m^3 or greater were reached 178 times at Wood Quay in Dublin City. Concentration levels in excess of 200 μg/m^3 have been recorded at several locations since 2000. The majority of these exceedances were located in Dublin County, and most occurred during the morning and evening heavy traffic periods.

NO_2 monitoring stations are distributed throughout Ireland in a variety of urban, suburban and rural locations, and in some locations near specific sources, such as roadside monitors (Ó Domhnaill *et al*., 2023). However, fixed-site monitoring is always limited to the number of locations where measurements can be obtained (Ó Domhnaill *et al*., 2023). Air quality modelling can provide information on concentrations of pollutants at a much larger number of locations, limited only by the availability of model input data and computing/data processing resources (Ó Domhnaill *et al*., 2023). In this project, air quality modelling was employed to calculate NO_2 concentrations at different locations to investigate potential mitigation strategies (Ó Domhnaill *et al*., 2023). The land use regression modelling approach employed made use of monitoring data collected throughout Ireland and examined the likely change in NO_2 concentrations expected as a result of changes in NO_2 source activities (Ó Domhnaill *et al*., 2023).

1.2 Health Impacts of Nitrogen Dioxide

The United States Environmental Protection Agency (US EPA) has published Integrated Science Assessments (ISAs) for a number of air pollutants. These establish the health impacts relating to each pollutant by analysing previous international research studies (US EPA, 2008, 2009, 2010, 2016). A major issue in determining health impacts is the potential for confounding factors to overestimate or underestimate the results, and their determination within the ISAs is based on the potential of those studies to account for and minimise potential confounding. (Confounding is where more than one pollutant is contributing to a health impact but there is difficulty in determining the effect caused by each pollution separately.) The determination of health impacts is based on the following categories:

- **causal** – studies where exposure concentration statistics are typical for the locations of the studies and the results are sufficient to conclude that the pollutant has health impacts independent of confounding factors/co-pollutants;
- **likely** – studies where exposure concentration statistics are typical for the locations of the studies and the pollutant's links to health effects have been confirmed but effects independent from co-pollutants cannot be fully established;
- **suggestive** – limited studies available where exposure concentration statistics are typical for the locations of the studies but confounding cannot be reduced, or sufficient studies are available but results are inconsistent on health impact links;
- **inadequate** – insufficient studies available with consistent and statistically strong results available to determine health impacts;
- **not likely** – studies covering wide ranges of concentrations typical for the locations of the studies have considered vulnerable groups of the population and consistently concluded that there are no health impacts linked to the pollutant at any concentration.

In the 2008 oxides of nitrogen ISA (US EPA, 2008), there was inadequate information available to determine links between most of the investigated health effects and NO_2 exposure, with only short-term and long-term exposure respiratory effects and short-term total mortality having sufficient studies to justify a likely causal or suggestive determination. However, the additional information available for the 2016 ISA (US EPA, 2016) had greatly increased and improved knowledge of health impacts across the board, with only the fertility, reproduction and pregnancy, and postnatal development categories remaining inadequate determination. There was sufficient new evidence since 2008 to determine that short-term exposure to NO_2 was independently linked to respiratory health effects (US EPA, 2016).

The Committee on the Medical Effects of Air Pollutants has published statements concerning health effects linked to NO_2 exposure and found that strong evidence is available confirming these links but that the issue of confounding cannot be fully removed (Committee on the Medical Effects of Air Pollutants, 2018). Results from these studies may still represent multi-pollutant effects using NO_2 as a marker, but there is sufficient evidence to suggest that NO_2 is a partial cause of the effects (Committee on the Medical Effects of Air Pollutants, 2018). A number of meta-analysis studies have been carried out linking NO_2 exposure with increases in respiratory- and cardiovascular-related hospital admissions and in mortality (Atkinson *et al*., 2014, 2018; Faustini *et al*., 2014; Mills *et al*., 2015; Huangfu and Atkinson, 2020).

1.3 Previous Related Research in Ireland

A number of previous research projects completed under the EPA's Environmental Research, Technological Development and Innovation (ERTDI) and Science, Technology, Research and Innovation for the Environment (STRIVE) programmes have investigated the levels and distribution of NO_2 concentrations in Ireland, including methods of assessment. Broderick *et al*. (2006) validated emissions and dispersion models for predicting roadside concentrations of pollutants in Ireland, including NO_2. Kelly (2006, 2011) applied the Regional Air Pollution Information and Simulation (RAINS) and Greenhouse Gas–Air Pollution Interactions and Synergies (GAINS) models in Ireland, which include oxides of nitrogen among the pollutants considered, as policy support tools. Morrin *et al*. (2015) developed improved inventories for NO_x emissions from transport and small-scale combustion installations in Ireland. Donnelly *et al*. (2019) developed an air quality forecast model for Ireland compatible with the Air Quality Index for Health that included the capability to forecast ambient NO_2 concentrations. The forecast model, as part of the same research, was further developed to produce national maps of annual and short-term NO_2 concentrations using land use regression.

1.4 Objectives

The objectives of the project were as follows:

1. Using currently available air pollution measurements and recent research results on the influence of meteorological and source variables (including wind direction, transport vehicle

characteristics and population mobility demands), the project aimed to identify a set of characteristics for the locations in Ireland that are at most risk of experiencing high levels of NO_2.

2. Using the Health Service Executive Primary Care Reimbursement Service (HSE-PCRS) prescribing database, the project aimed to establish baseline data linking NO_2 levels with the prescription of drugs used to treat asthma and chronic obstructive airways disease. The intention is to research methodologies to facilitate the collection of prospective data in the future.
3. By exploring the Growing Up in Ireland (GUI) and the Irish Longitudinal Study on Ageing (TILDA, 2018) databases, the project aimed to investigate if relationships exist between prevalence of respiratory symptoms in vulnerable groups, e.g. children, the elderly and the socio-economically deprived, and NO_2 levels, within database constraints.
4. By reviewing the policies and strategies being implemented by other countries to bring NO_2 within compliance levels, the project aimed to identify a set of effective and efficient solutions to reduce and mitigate the impact of the transport sector on NO_2 levels in Ireland.

2 Analysis of Nitrogen Dioxide Concentrations and Rates of Dispensing Prescriptions of Respiratory Items

The aim of this part of the work programme was to examine respiratory item prescription rates and determine if associations exist with modelled local NO_2 levels. The prescription data were obtained from the HSE-PCRS (publicly insured – medical card) from September 2014 to December 2016. The monthly prevalence of prescribing respiratory medications to a range of age cohorts in each of the 32 health regions (by local health offices (LHOs)) of Ireland was obtained. Daily EPA monitoring levels of particulate matter consisting of particles with diameter of 2.5 μm or less ($PM_{2.5}$) and NO_2 were used to provide a mean monthly value for these pollutants for four regions, chosen because of the availability of consistent data. While the project's focus was on the health impacts of NO_2, the team also had the opportunity to consider $PM_{2.5}$ in this analysis. The primary outcome examined was the prevalence of individuals dispensed a respiratory item (defined as an individual that received at least one dispensed respiratory item in that month).

2.1 Methods

The HSE-PCRS and NO_2 data were used to link NO_2 levels with the rates of prescription of drugs used to treat asthma and chronic obstructive airways disease. Negative binomial regression with count data was used to estimate the association between the prescribing rates and levels of NO_2.

Subgroup analyses examined the monthly prevalence of individuals dispensed an oral steroid or a short-acting bronchodilator. All analyses were repeated using the count of items dispensed/eligible population. Negative binomial regression with count data was used to estimate the association between the variables of interest and the outcomes, adjusting for the seasonal nature of the dispensing data (winter, defined as November–February inclusive). The number of individuals eligible for General Medical Services (GMS) in that month for each LHO was used as an offset.

Four regions were selected based on the availability of consistent data: South Dublin, North Cork, Dublin North and Dublin North West. The prescription data were obtained from GMS (medical card) dispensing data from September 2014 to December 2016 for the four LHOs. The air pollution data were obtained from the EPA monitors based in the region; if a monitor was not available in the region, a monitor in a similar location type was used. Average monthly values were calculated for each of the pollutants so that the association with the monthly prescription rates could be analysed. For South Dublin, the $PM_{2.5}$ readings were taken from the Wicklow/Bray monitor, and the Dún Laoghaire monitor was used for NO_2. In the case of Dublin North and Dublin North West, the Fingal monitor was used for $PM_{2.5}$ data and the Swords and Blanchardstown monitors were used for the NO_2 measurements, respectively.

Air pollution monitors were not available in the North Cork region and therefore alternative monitors in similar types of regions were used. From an assessment of the locations of all EPA monitors, the $PM_{2.5}$ monitor based in Longford was concluded to be located in a similar area type to that of North Cork and its data were used in the analysis. In the case of NO_2, two monitors were deemed to be in areas similar to North Cork, Monaghan/Kilkitt and Portlaoise, resulting in two modelling scenarios: (1) the North Cork 1 model, which used $PM_{2.5}$ data from the Longford monitor and NO_2 data from the Monaghan/Kilkitt monitor; and (2) the North Cork 2 model, which used $PM_{2.5}$ data from the Longford monitor and NO_2 data from the Portlaoise monitor. Care should be taken with the interpretation of the results in these cases.

The following outcomes were assessed:

- monthly prevalence of patients dispensed a respiratory item (defined as a patient who was dispensed at least one respiratory item in the month);
- monthly rate of dispensing respiratory items to the GMS-eligible population;

- monthly prevalence of patients dispensed an oral steroid (e.g. prednisolone) (defined as a patient that was dispensed at least one oral steroid in that month);
- monthly rate of dispensing oral steroid items to the GMS-eligible population;
- monthly prevalence of patients dispensed a short-acting bronchodilator (e.g. salbutamol) (defined as a patient who was dispensed at least one short-acting bronchodilator in that month);
- monthly rate of dispensing short-acting bronchodilator items to the GMS-eligible population.

2.2 Results

Negative binomial regression with count data was used to estimate the association between the variables of interest ($PM_{2.5}$ and NO_2) and the above outcomes, adjusting for the seasonal nature of the dispensing data. The models were adjusted for age and for the winter period, defined as November–February inclusive. A subgroup analysis was undertaken for each of the outcomes, restricting the cohort to children aged 0–4 years. In addition, a sensitivity analysis was undertaken, limiting the data to non-winter months only (i.e. March–October inclusive), to examine whether the association between $PM_{2.5}$ or NO_2 and the outcome of interest was sufficiently estimated in the full model when adjusted for winter months.

All model outcomes are presented as rates, i.e. as either a count of patients dispensed a respiratory item per head of GMS-eligible population or a count of items dispensed per head of GMS-eligible population. The model output is presented as an incidence rate ratio. This is the estimated rate ratio for a 1-unit increase in the variable of interest when the other variables are held constant in the model. For example, if the incidence rate ratio for $PM_{2.5}$ is 1.04, this means that, if the $PM_{2.5}$ level were to increase by 1 unit, the outcome of interest would be expected to increase by a factor of 1.04 (or 4%), while holding all other variables in the model constant.

Table 2.1 shows the association between the variables of interest ($PM_{2.5}$, NO_2 and winter) and the prevalence of patients dispensed a respiratory item. Table 2.2 shows the association between the variables of interest and the rate of dispensing respiratory items.

Table 2.1. Age-adjusted incidence rate ratio for the prevalence of patients dispensed a respiratory item

Model	$PM_{2.5}$ monthly average	NO_2 monthly average	Winter
South Dublin	The model did not converge		
North Cork 1	1.01*	1.01	1.08*
North Cork 2	1.01*	0.99*	1.08*
Dublin North	1.00	1.00	1.05*
Dublin North West	1.01*	1.00	1.06*

***Statistically significant association (*p*-value < 0.05).**

Table 2.2. Age-adjusted incidence rate ratio for the rate of dispensing respiratory items

Model	$PM_{2.5}$ monthly average	NO_2 monthly average	Winter
South Dublin	1.00	1.00	1.03*
North Cork 1	1.01*	1.01	1.07*
North Cork 2	1.01*	0.99*	1.08*
Dublin North	1.00	1.00	1.05*
Dublin North West	1.01*	1.00	1.05*

***Statistically significant association (*p*-value < 0.05).**

Winter has the strongest association with outcome, in that the prevalence of patients dispensed a respiratory item increases by 5–8% in winter (November–February) compared with the rest of the year (Table 2.1). Similarly, the rate of dispensing respiratory items increased by 3–8% in winter (Table 2.2). For every 1-unit increase in $PM_{2.5}$, the prevalence of patients dispensed a respiratory item increases by a factor of 1.01 (1%) in North Cork and North West Dublin, adjusting for the impact of winter. The rate of dispensing respiratory items increases by a similar amount. No association is evident between NO_2 and either outcome, and when the Portlaoise value of NO_2 is used as a proxy for North Cork (North Cork 2) there is a negative association.

The next analysis completed was similar to the first but only those aged 0–4 years were included. The results are presented in Tables 2.3 and 2.4. In this case, the association with winter is greatly increased, with the prevalence of children dispensed a respiratory item between 26% and 44% greater in winter than during the rest of the year. Similarly, the rate of dispensing respiratory items is also much greater, i.e. 26–39% higher, in the winter period.

Table 2.3. The incidence rate ratio for the prevalence of children aged 0–4 years dispensed a respiratory item

Model	$PM_{2.5}$ monthly average	NO_2 monthly average	Winter
South Dublin	1.03	1.01	1.26*
North Cork 1	1.03	1.00	1.41*
North Cork 2	1.03*	0.99	1.44*
Dublin North	1.04*	1.00	1.34*
Dublin North West	1.05*	1.00	1.32*

***Statistically significant association (*p*-value < 0.05).**

Table 2.4. Incidence rate ratio for the rate of dispensing respiratory items to children aged 0–4 years

Model	$PM_{2.5}$ monthly average	NO_2 monthly average	Winter
South Dublin	1.04	1.02	1.26*
North Cork 1	1.03	0.97	1.34*
North Cork 2	1.04*	0.99	1.39*
Dublin North	1.03*	1.00	1.33*
Dublin North West	1.05*	1.00	1.26*

***Statistically significant association (*p*-value < 0.05).**

In Dublin North and Dublin North West, with every 1-unit increase in $PM_{2.5}$ there is an increase in the prevalence of children aged 0–4 years dispensed a respiratory item of 4% and 5%, respectively, adjusting for the impact of winter. The South Dublin and North Cork 1 models show no significance for $PM_{2.5}$, as is the case for all NO_2 models.

The focus of the next analysis was on the prescription of oral steroids. The age-adjusted results are presented in Tables 2.5 and 2.6. Again, winter has the strongest association with outcome, in that the prevalence of patients dispensed an oral steroid increases by 14–20% in winter compared with the rest of the year (Table 2.5). Similarly, the rate of dispensing increases by 14–22% in winter (Table 2.6).

For every 1-unit increase in $PM_{2.5}$, the prevalence of patients dispensed an oral steroid increases by a factor of 1.01 to 1.03 (1–3%) depending on region, adjusting for the impact of winter. South Dublin is the only region not showing statistical significance in this case. Similar increases are observed in the rate of dispensing oral steroid items. No association with NO_2 is evident in most regions, and when the Portlaoise value of NO_2 is used as a proxy for North Cork (North Cork 2) a negative association is observed.

Table 2.5. Age-adjusted incidence rate ratio for the prevalence of patients dispensed an oral steroid

Model	$PM_{2.5}$ monthly average	NO_2 monthly average	Winter
South Dublin	1.01	1.00	1.14*
North Cork 1	1.02*	1.01	1.18*
North Cork 2	1.03*	0.99*	1.20*
Dublin North	1.01*	1.00	1.15*
Dublin North West	1.02*	1.00	1.15*

***Statistically significant association (*p*-value < 0.05).**

Table 2.6. Age-adjusted incidence rate ratio for the rate of dispensing oral steroid items

Model	$PM_{2.5}$ monthly average	NO_2 monthly average	Winter
South Dublin	1.01	1.00	1.14*
North Cork 1	1.02*	1.01	1.19*
North Cork 2	1.03*	0.99*	1.22*
Dublin North	1.01*	1.00	1.14*
Dublin North West	1.02*	1.00	1.14*

***Statistically significant association (*p*-value < 0.05).**

A similar analysis was completed for the 0–4 years age group, the results of which are presented in Tables 2.7 and 2.8. Again, there is a much greater association between winter and both outcomes. In the winter season (November–February), the prevalence of children dispensed an oral steroid is 42–70% higher than during the rest of the year. Similarly, the rate of dispensing is 42–75% higher in the winter period. For every 1-unit increase in $PM_{2.5}$, there is an increase of 6–7% in both the prevalence of children aged 0–4 years dispensed an oral steroid in most regions and the rate of dispensing, adjusting for the impact of winter. No association with NO_2 is evident.

The final set of analyses focused on the prescription of short-acting bronchodilators. Tables 2.9 and 2.10 show the results for the age-adjusted analysis and Tables 2.11 and 2.12 show the results of a similar analysis conducted on the 0–4 years age group. In the case of the age-adjusted analysis, winter has the strongest association with outcome, in that both the prevalence of patients dispensed a short-acting bronchodilator and the rate of dispensing short-acting bronchodilator items increases by 3–10% in winter

Table 2.7. Incidence rate ratio for the prevalence of children aged 0–4 years dispensed an oral steroid

Model	$PM_{2.5}$ monthly average	NO_2 monthly average	Winter
South Dublin	1.04	1.00	1.70*
North Cork 1	1.06*	1.01	1.42*
North Cork 2	1.08*	0.98	1.47*
Dublin North	1.07*	1.00	1.47*
Dublin North West	1.07*	1.00	1.44*

***Statistically significant association (*p*-value < 0.05).**

Table 2.8. Incidence rate ratio for the rate of dispensing oral steroid items to children aged 0–4 years

Model	$PM_{2.5}$ monthly average	NO_2 monthly average	Winter
South Dublin	1.05	1.00	1.75*
North Cork 1	1.06*	1.01	1.45*
North Cork 2	1.08*	0.98	1.49*
Dublin North	1.07*	1.00	1.45*
Dublin North West	1.07*	1.00	1.42*

***Statistically significant association (*p*-value < 0.05).**

Table 2.9. Age-adjusted incidence rate ratio for the prevalence of patients dispensed a short-acting bronchodilator

Model	$PM_{2.5}$ monthly average	NO_2 monthly average	Winter
South Dublin	1.00	1.01	1.03*
North Cork 1	1.01*	1.01	1.09*
North Cork 2	1.02*	0.99*	1.10*
Dublin North	1.00	1.00	1.05*
Dublin North West	1.01*	1.00	1.07*

***Statistically significant association (*p*-value < 0.05).**

(Table 2.9). For every 1-unit increase in $PM_{2.5}$, the prevalence of patients dispensed a short-acting bronchodilator item increases by a factor of 1.01 to 1.02 (1–2%) in North Cork and Dublin North West, adjusting for the impact of winter. No association is seen for South Dublin or Dublin North (Table 2.9). Similar results are observed in the rate of dispensing short-acting bronchodilator items (Table 2.10).

No association is evident between NO_2 and either outcome, and when the Portlaoise value of NO_2 is used as a proxy for North Cork (North Cork 2)

Table 2.10. Age-adjusted incidence rate ratio for the rate of dispensing short-acting bronchodilator items

Model	$PM_{2.5}$ monthly average	NO_2 monthly average	Winter
South Dublin	1.00	1.00	1.03*
North Cork 1	1.01*	1.01	1.09*
North Cork 2	1.02*	0.99*	1.10*
Dublin North	1.00	1.00	1.06*
Dublin North West	1.01*	1.00	1.06*

***Statistically significant association (*p*-value < 0.05).**

Table 2.11. Incidence rate ratio for the prevalence of children aged 0–4 years dispensed a short-acting bronchodilator

Model	$PM_{2.5}$ monthly average	NO_2 monthly average	Winter
South Dublin	1.03	1.02	1.24
North Cork 1	1.03	1.01	1.52*
North Cork 2	1.04*	0.99	1.54*
Dublin North	1.04*	1.00	1.34*
Dublin North West	1.05*	1.00	1.32*

***Statistically significant association (*p*-value < 0.05).**

Table 2.12. Incidence rate ratio for the rate of dispensing short-acting bronchodilator items to children aged 0–4 years

Model	$PM_{2.5}$ monthly average	NO_2 monthly average	Winter
South Dublin	1.03	1.02	1.27
North Cork 1	1.03	1.01	1.49*
North Cork 2	1.04	0.99	1.50*
Dublin North	1.04*	1.00	1.37*
Dublin North West	1.05*	1.00	1.34*

***Statistically significant association (*p*-value < 0.05).**

a negative association is observed (Tables 2.9 and 2.10).

As shown in Tables 2.11 and 2.12, there is a much greater association between winter and both outcomes among children aged 0–4 years, with the prevalence of children dispensed a short-acting bronchodilator 32–54% higher and the rate of dispensing 34–50% higher in the winter period. For every 1-unit increase in $PM_{2.5}$, there is an increase of 4–5% in both outcomes for Dublin North and Dublin North West, adjusting for the impact of winter. There were mixed results for North Cork and no statistical association between $PM_{2.5}$ and either outcome in South Dublin. No associations were evident in the case of NO_2 for either outcome.

2.3 Conclusions

Winter was the variable with the strongest association with the prescription dispensing outcomes, and this was most pronounced in the analyses undertaken on the 0–4 years age category. For most of the outcomes investigated, there was no association evident between the levels of NO_2 and the outcome of interest. This may be due to limitations of the data. Only four regions could be examined because of issues with data consistency. Some of the areas considered are large geographically, and available NO_2 monitors were limited. The NO_2 measurements were averaged over a month, as the dispensing data were aggregated at the monthly level.

In most regions, there was an association between $PM_{2.5}$ and each outcome of interest, taking account of the impact of winter on dispensing. This was most pronounced with oral steroids and especially in the subgroup analyses undertaken in the 0–4 years age group. It is possible that the potential correlation between $PM_{2.5}$ and NO_2 and the greater association of $PM_{2.5}$ with the outcomes of interest have overshadowed an association of NO_2 with the outcomes.

3 Analysis of Nitrogen Dioxide Concentrations and Asthma Prevalence in the Over-50s

This chapter of the report presents the results of an analysis (Carthy *et al*., 2020) conducted using the TILDA database, which hosts health data and other socio-economic data of 8162 adults aged 50+ in Ireland (Kearney *et al*., 2011; Donoghue *et al*., 2018). The analysis was completed in collaboration with the Economic and Social Research Institute (ESRI). The TILDA data were used to determine if associations exist between estimated NO_2 levels in the area where the database participants reside and their health, using the model developed in Naughton *et al*. (2018). In the sample considered, 9% of individuals indicated that a doctor had previously diagnosed them with asthma, whereas the proportion prescribed medication for the condition was smaller, at 6.9%. Therefore, two health variables were used in the analysis: (1) self-reports of asthma diagnosis and (2) the use of relevant medications. Logistic regression was used to model the relationships between the health variables and the estimated NO_2 levels. The distribution of estimated exposure to NO_2 is presented in Figure 3.1, in which it can be seen that most respondents are exposed to relatively low doses of NO_2.

Of the TILDA sample, 54% were female and 46% were male. Fifty-seven per cent were in the 50–64 years age bracket, with 36% in employment. A large proportion (56%) of the sample had smoked at some point in their lives, with 18% reporting that they currently smoked. Most of the sample were mobile, with only approximately 7% reporting difficulty walking 100 m because of a physical or mental health condition.

The results of the logistic regression analysis are reported as average marginal effects of a given variable on the probability of suffering from asthma. The results from model 1 (asthma self-reports) suggest that a 1 part per billion (ppb) increase in NO_2 concentration is associated with a 0.24 percentage point increase (95% confidence interval (CI) 0.06 to 0.422) in the probability of reporting an asthma diagnosis for those with exposure to levels of < 13.1 ppb. For those living in areas exposed to levels higher than 13.1 ppb, there was an effect size of an order of magnitude higher, at 2.4 percentage points (95% CI –0.493 to 5.31), but also a larger standard

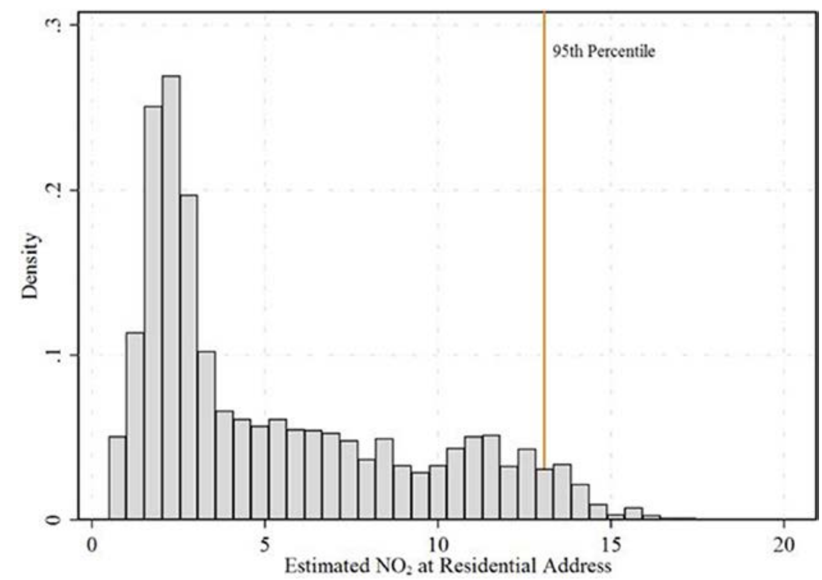

Figure 3.1. Distribution of NO_2 exposure among TILDA respondents. Source: Carthy *et al*., 2020, Local NO_2 concentrations and asthma among over-50s in Ireland: a microdata analysis, *International Journal of Epidemiology* 49(6): 1899–1908, https://doi.org/10.1093/ije/dyaa074. Reproduced by permission of Oxford University Press on behalf of the International Epidemiological Association.

error. In the case of model 2 (medications), a 1 ppb increase in NO_2 concentration was associated with a 0.26 percentage point increase (95% CI 0.049 to 0.3) in the probability of requiring medication for asthma. Associations between local air pollution and asthma among older adults were found at relatively low concentrations.

4 Modelling of Mitigation Strategies using Enhanced Land Use Regression

Objective 4 of the project's work programme considered what type of mitigation strategies/policies might be used in the transport sector to bring about reductions in ambient NO_2 concentrations. As part of this process, the project aimed to identify the main environmental, meteorological and traffic-related conditions that contribute to high NO_2 levels at various locations throughout Ireland (Ó Domhnaill *et al*., 2023). An existing land use regression (LUR) model, based on the original work of Naughton *et al*. (2018), was enhanced. This model calculates NO_2 concentrations using a wind sector land use regression (WS-LUR) model. The enhancement to the model, completed as part of this project, involved additional data describing the national distribution of vehicle characteristics, such as vehicle fleet breakdown, Euro classifications (based on EU emission standards) and fuel types. This model was used to deliver on objectives 1 and 4. The model and how it was improved are summarised below and is detailed in Appendix 1.

4.1 Land Use Regression Model Development

This required the synthesis of a considerable amount of data in the form of a LUR-based model that can be used to determine the NO_2 concentration at any location in Ireland (Ó Domhnaill *et al*., 2023). The LUR model was created by combining existing data on land use and traffic with historical air quality data, and it can be used to predict changes in air quality due to changes in land use or traffic characteristics (Ó Domhnaill *et al*., 2023).

The LUR modelling procedure developed by Naughton *et al*. (2018) was retained, but the capability of the model to capture the effects of vehicle emissions was enhanced (Ó Domhnaill *et al*., 2023). This involved including additional data describing the national distribution of vehicle characteristics, including vehicle fleet breakdown, Euro classifications and fuel types (Ó Domhnaill *et al*., 2023). These data have been introduced to further strengthen the model's representation of local measured concentrations and to enable the analysis of mitigation strategies that reduce emissions in specific locations or from specific classes of vehicle (Ó Domhnaill *et al*., 2023).

4.1.1 Model implementation

The original WS-LUR model (Naughton *et al*., 2018) was developed to create national maps of NO_2 concentrations, but its methodology did not distinguish between the characteristics of traffic on different roads or in different years (Ó Domhnaill *et al*., 2023). In this project, the WS-LUR model was enhanced to take into account variations in vehicle types and fuels, to facilitate the investigation of potential mitigation strategies (Ó Domhnaill *et al*., 2023).

The model has two modes of operation (Ó Domhnaill *et al*., 2023). The first is an automatic calculation where the user selects from one of the pre-set years included in the model (2016 to 2018), and the model calculates NO_2 concentrations using the data saved in the background (Ó Domhnaill *et al*., 2023). The other mode is the manual entry method in which the user enters the required data for a specific location and the resultant concentration is calculated (Ó Domhnaill *et al*., 2023). This mode supports the calculation of future or past concentrations (Ó Domhnaill *et al*., 2023).

The model contains a section that summarises variable values (meteorological, land use, commercial properties, the inverse distance-weighted vehicle kilometres travelled (IDWVKT) and road density) in each wind direction sector as well as the concentration contribution from each wind direction sector. Other sections within the model allow the user to analyse concentrations in future or past time periods and also to analyse potential mitigation measures by altering the values of the meteorological, land use, commercial properties, IDWVKT and road density variables within the model. The step-by-step process for calculating the NO_2 concentration at a location is shown in Figure 4.1. Model validation and comparisons between monitored and modelled concentrations are presented in Appendix 1.

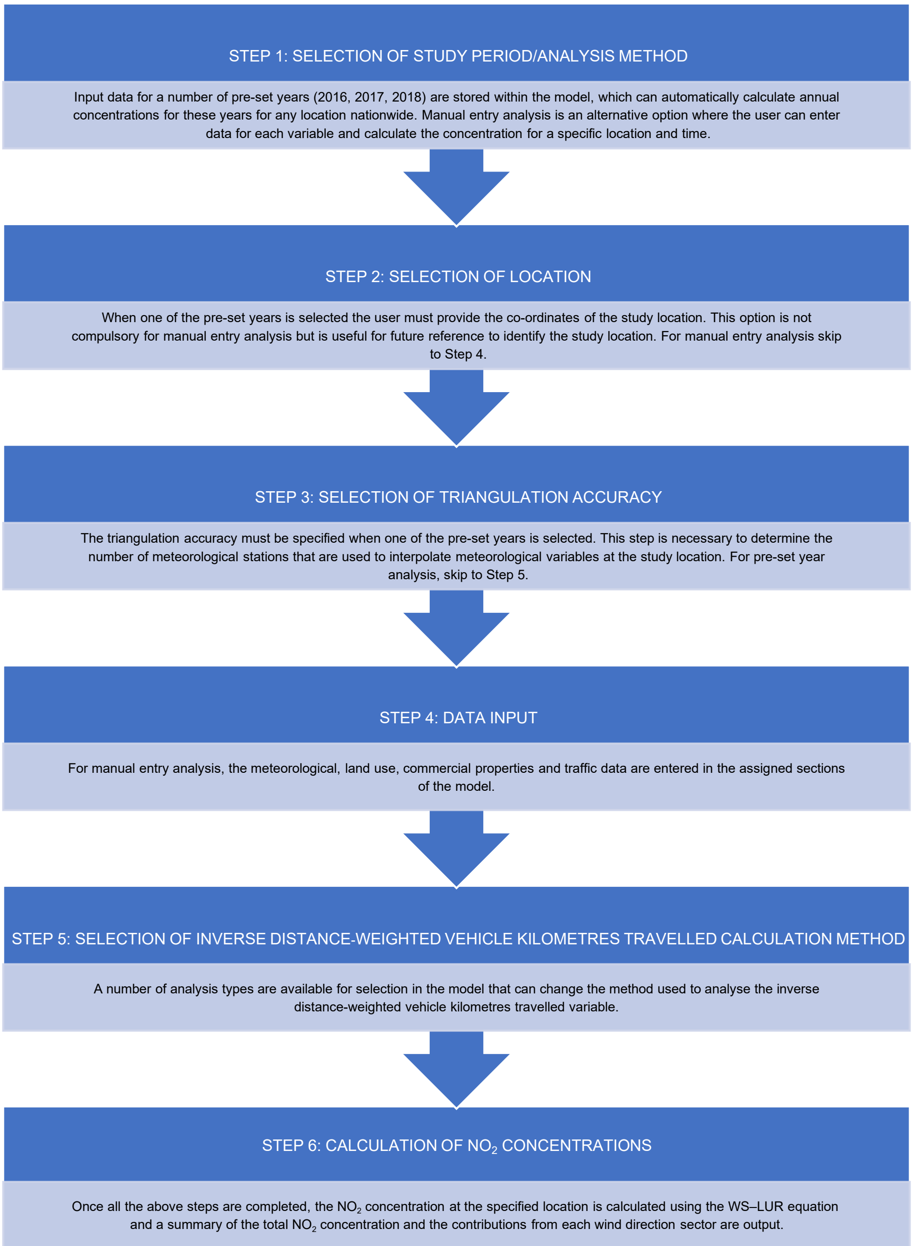

Figure 4.1. Improved WS-LUR model input and step-by-step process for calculating NO_2 concentration.

4.2 Modelling of Mitigation Strategies using Enhanced Land Use Regression Model

As mentioned previously, the majority of NO_2 emissions in Ireland are generated by the transport sector (EPA, 2019c). Objective 4 of the project's work programme was therefore to consider what type of mitigation strategies/policies might be used in the transport sector to bring about reductions in ambient NO_2 concentrations. A review of strategies being implemented by other countries to bring NO_2 concentrations within compliance levels was examined. The measures proposed in the Dublin Region Air Quality Plan (Dublin City Council *et al.*, 2021), including the 15-minute neighbourhood concept, parking controls and standards, electric vehicle charging strategies, the introduction of clean-air/low-emission zones (LEZs), remote/flexible working and behavioural change campaigns, were also reviewed. The aim was to identify a set of effective and efficient solutions to reduce and mitigate the impact of the transport sector on NO_2 levels in Ireland.

Of the strategies reviewed, the following four were selected for investigation because of their potential to reduce emissions, the existence of successful examples of their implementation elsewhere and the capability of the model to capture before and after scenarios in each case effectively:

1. the relocation of businesses from a suburban location to a semi-rural area – the example used was to relocate Blanchardstown Business Hub to Kildare;
2. the removal of diesel vehicles from the small public service vehicle (SPSV) fleet (cars) and large public service vehicle (LPSV) fleet (buses);
3. a bypass route – the example used was the proposed Cork ring road;
4. an LEZ in Dublin.

The enhanced WS-LUR model was used to evaluate the strategies. In addition to the mitigation strategies listed above, the impact of reduced transport demand during the first COVID-19 lockdown was also analysed, to determine changes in NO_2 levels.

4.2.1 Relocation of Blanchardstown Business Hub to Kildare

The Central Statistics Office has identified that a large proportion of the working population in each of the five major cities in Ireland commute from regions outside the city and its suburbs (Central Statistics Office, 2016). The ratio of people working in their town of usual residence to people commuting to work is approximately 50:50 in both Limerick and Galway, while in Cork and Waterford this ratio is 59:41 and 54:46, respectively. The ratio for Dublin is significantly higher, at 75:25, but the number of people commuting is also significantly greater than for the other cities, at 130,447, with the next largest population commuting into a city being 41,433 in Cork City (Central Statistics Office, 2016).

Historically, businesses locate themselves in or close to cities to take advantage of larger markets and better transport links. However, the requirement for a significant proportion of the population to commute long distances to work in those businesses results in congestion and higher levels of air pollution on commuter routes and in the areas in which the jobs are based. The business hub relocation mitigation measure aimed to assess if relocating businesses from an area of relatively high air pollution would result in improvements in air quality in the original location of the businesses and also on commuter routes, as a result of reduced traffic levels. The modelling considered the relocation of only businesses that are not dependent on the specific locale to carry out their activities. It did not include businesses providing essential local services such as health and retail services to the population of the surrounding area.

A number of factors highlighted Blanchardstown as an area that would benefit from such a strategy. The EPA monitoring station at Blanchardstown continues to record annual average NO_2 concentrations of approximately 30 $\mu g/m^3$ – higher than any other station located outside the Dublin city centre area. It is located in close proximity to the M50/N3 interchange. This annual average concentration is on par with the monitoring stations recording the highest NO_2 concentrations within the Dublin city centre region since 2011 (Winetavern Street and Coleraine Street). Hourly maximum concentrations in the region of 200 $\mu g/m^3$ have been measured year on year at Blanchardstown since 2011, and it is one of the stations that has a large number of recordings above the lower assessment threshold (> 100 $\mu g/m^3$) and upper assessment threshold (> 140 $\mu g/m^3$) concentrations since 2011 (EU, 2008).

Data

Traffic flow data for the relocation of businesses from Blanchardstown scenario were based on outputs from the East Regional Model of the National Transport Authority (NTA) for roads of all standards (motorway, national, rural, local, unclassified) within Leinster and parts of Ulster (NTA, 2020). (For the purposes of this report, this scenario will be called the Blanchardstown Business Hub relocation.) Data from all EPA monitoring stations located within the confines of the east region of the NTA model were considered in this analysis. A number of additional locations were included in the analysis, as the numbers of EPA monitoring stations located close to the original and new business locations were limited. Two additional locations west (Tyrrelstown) and east (Blanchardstown Business Campus) of the Blanchardstown Business Hub were identified, as were three additional locations around Kildare Town – one in the town centre (Saint Brigid's Cathedral in Market Square), one south of the town (south of the M7 motorway's Kildare interchange) and one to the west of the town (Kildare Village/ south of the M7 motorway's Kildare interchange).

All locations considered were identified as areas where considerable traffic flow changes could occur close to the original and new business locations. Quantifying the changes in ambient NO_2 concentrations at these key locations supported the overall evaluation of whether the positive effects on air quality at one location were outweighed by potential negative concentration changes elsewhere.

Data on commercial properties were retrieved from the EPA geographic information system (GIS) department and An Post/GeoDirectory (GeoDirectory, 2020) in ArcGIS points file format. The data comprised records of all commercial properties in Ireland as of 2019 and included details such as location and business type. The analysis modelled the relocation of all business types that were not dependent on the locale or were not businesses that provided services to the local public such as grocery shopping, health and retail services and food facilities. The resultant changes in traffic flows were captured by traffic modelling using the NTA model (NTA, 2020). In this modelling, work trip attractions were relocated at the Central Statistics Office "small area" level from the Blanchardstown region to the Kildare Town region. (Trip attractions are the number of trips attracted to a particular area, e.g. for travel to work.) This resulted in changes to modelled route traffic flows due to the changes in the origin/destination of journeys to and/or from the attractions.

The NTA model covers four job attraction categories, and all job types are accounted for in one of the categories. The categories are health or non-health, food or non-food, non-grocery shopping or all jobs excluding non-grocery shopping, and retail or non-retail. The job attractions defined as non-health, non-food, all jobs excluding non-grocery shopping and non-retail were the focus of this analysis. The third-level education attractions in the Blanchardstown Business Hub region were also identified for relocation to Kildare Town, as a number of the businesses could be dependent on the third-level institution for future employees and summer work placements as part of course programmes. The total number of job attractions identified for relocation was then equally split between the three Central Statistics Office small areas, which covered Kildare Town and surrounding areas. The resultant traffic flow outputs from the NTA model were provided by the NTA.

The *Irish Bulletin of Vehicle and Driver Statistics* report, published by the Department of Transport, Tourism and Sport (2020), was used to characterise the vehicle fleet for 2019. Details of fuel type, unladen weights, engine capacities and year when first licensed are available in the *Irish Bulletin of Vehicle and Driver Statistics* and can be used to determine the Euro class breakdown of each vehicle category (i.e. passenger cars, light commercial vehicles (LCVs), heavy-duty vehicles (HDVs), etc.) (Ó Domhnaill *et al*., 2023). These details were then used to determine the assumed NO_2 emission weighting for each vehicle type in 2019. The 2019 vehicle fleet consisted of 77% passenger cars, 12% LCVs, 1% HDVs, 0.7% SPSVs, 0.4% LPSVs and 2% motorcycles. The other 6% of vehicles were agricultural and exempt vehicles and were not modelled.

The meteorological data used in this analysis were obtained from the Met Éireann historical database and included data for all monitoring stations, including offshore stations, for 2019 (Met Éireann, 2019).

Results

The results include traffic flow changes resulting from the relocation of businesses from Blanchardstown to Kildare Town and its surrounds for each vehicle type category (annual average daily traffic (AADT), car/taxi, light goods vehicle (LGV), heavy goods vehicle (HGV) and LPSV) for every road in the NTA East Regional Model. Figures 4.2 and 4.3 show the results for AADT and LGVs. Overall, the relocation generated lower flows on the major (national and motorway) routes into Dublin, with reductions of up to 10% in AADT observed on the majority of road sections, as shown in Figure 4.2. The M1/N1 route between Belfast and Dublin, M3/N3 route between Cavan and Dublin, M4/N4 route between Sligo/Galway and Dublin, M7/N7 route between Kildare and Dublin, and M9 route between Waterford and east of Kildare Town experienced reductions in the range of 1–10% in car/taxi flows, more than a 10% reduction in LGVs and reductions of more than 100 vehicles per day in the HGV and LPSV categories. Reductions in car/taxi flows in the range of 1–10% were observed on the majority of routes. As expected, as a result of the increased job attractions within the Kildare Town region, flows on routes towards the town increased by more than 10% in the AADT, car/taxi and LGV vehicle

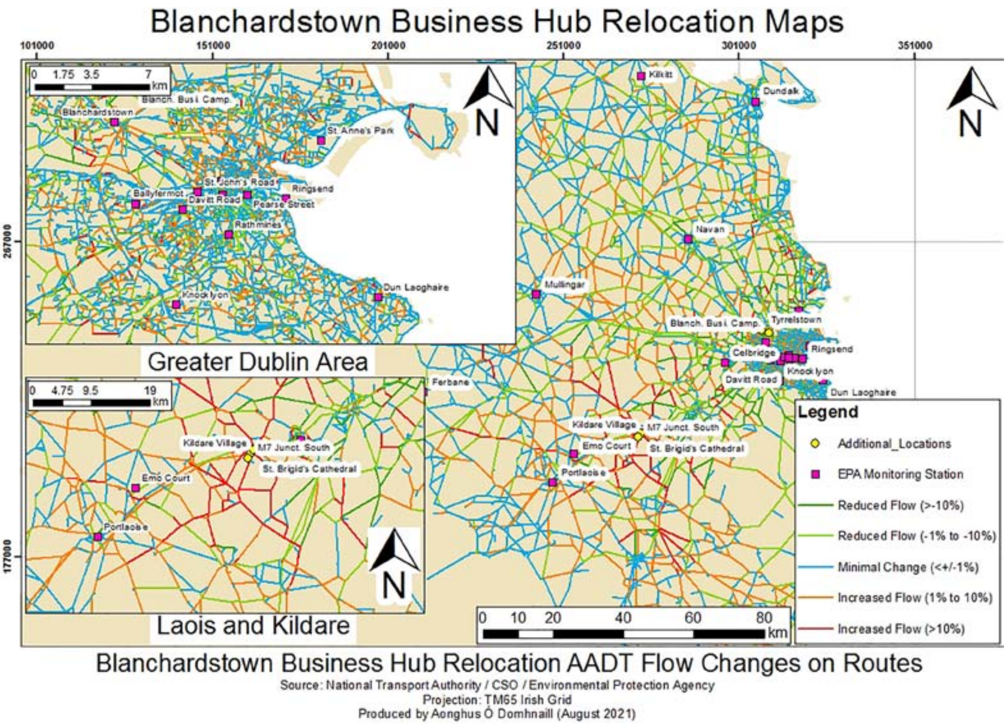

Figure 4.2. Blanchardstown Business Hub relocation: AADT flow changes on routes. Data sources: Central Statistics Office, Ireland, licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/); NTA, Ireland, permission granted; © Tailte Éireann/Government of Ireland, Copyright Permit No. MP 003023.

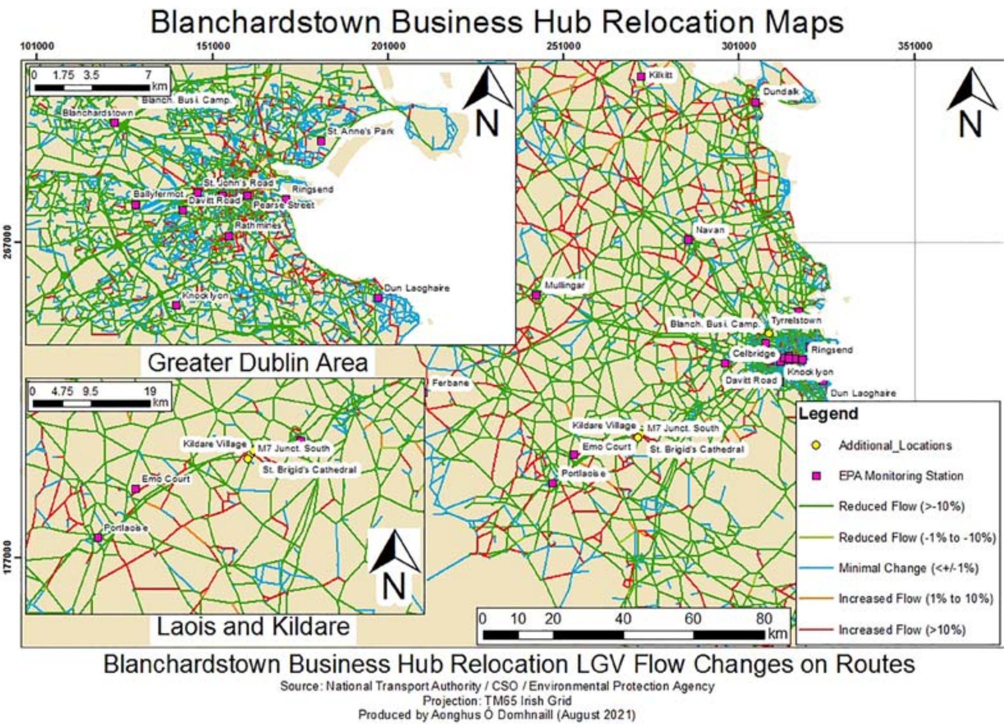

Figure 4.3. Blanchardstown Business Hub relocation: LGV flow changes on routes. Data sources: Central Statistics Office, Ireland, licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/); NTA, Ireland, permission granted; © Tailte Éireann/Government of Ireland, Copyright Permit No. MP 003023.

categories (Figure 4.3), and the number of HGVs and LPSVs on routes towards Kildare Town also increased by more than 100 vehicles per day.

Figure 4.4 shows the resultant changes in ambient NO_2 concentrations at all monitoring stations and additional locations. Significant reductions were experienced in the Dublin city centre locations; Coleraine Street, Pearse Street, Ringsend, St John's Road and Winetavern Street recorded reductions of 1.2, 0.7, 0.5, 1.9 and 0.9 µg/m³, respectively, associated with reduced traffic levels. Varying results were achieved at the other Dublin monitoring stations located outside the city centre. The Dún Laoghaire and Davitt Road monitoring station locations experienced increases of 0.2 and 2.3 µg/m³, respectively, mainly due to the changes in traffic flows, which led to substantial increases in IDWVKT in the predominant west and south-west wind direction sectors. The remaining Dublin monitoring station locations all displayed improved air quality, with reductions in the range of 0.3 and 1.7 µg/m³.

At receptors close to the original business locations (i.e. the Blanchardstown EPA monitoring station and the Tyrrelstown and Blanchardstown Business Campus additional locations), the modelled reductions in NO_2 concentrations ranged from 0.4 to 1.3 µg/m³, with the 1.3 µg/m³ reduction occurring at the Blanchardstown EPA monitoring station. This is an important result given that NO_2 concentrations measured at this station have been close to the WHO's annual mean limit (in operation up to September 2021), with hourly maximum concentrations in the region of 200 µg/m³. In September 2021, as the work on this project was drawing to a close, the WHO changed its guideline values for NO_2 to an annual mean of 10 µg/m³ and a 24-hour mean of 25 µg/m³ (WHO, 2021; Ó Domhnaill *et al.*, 2023). In the context of these new guidelines, the improved air quality resulting from the modelled mitigation strategy carries extra significance. The changes in concentrations at the additional locations identified for this analysis ranged from an increase of

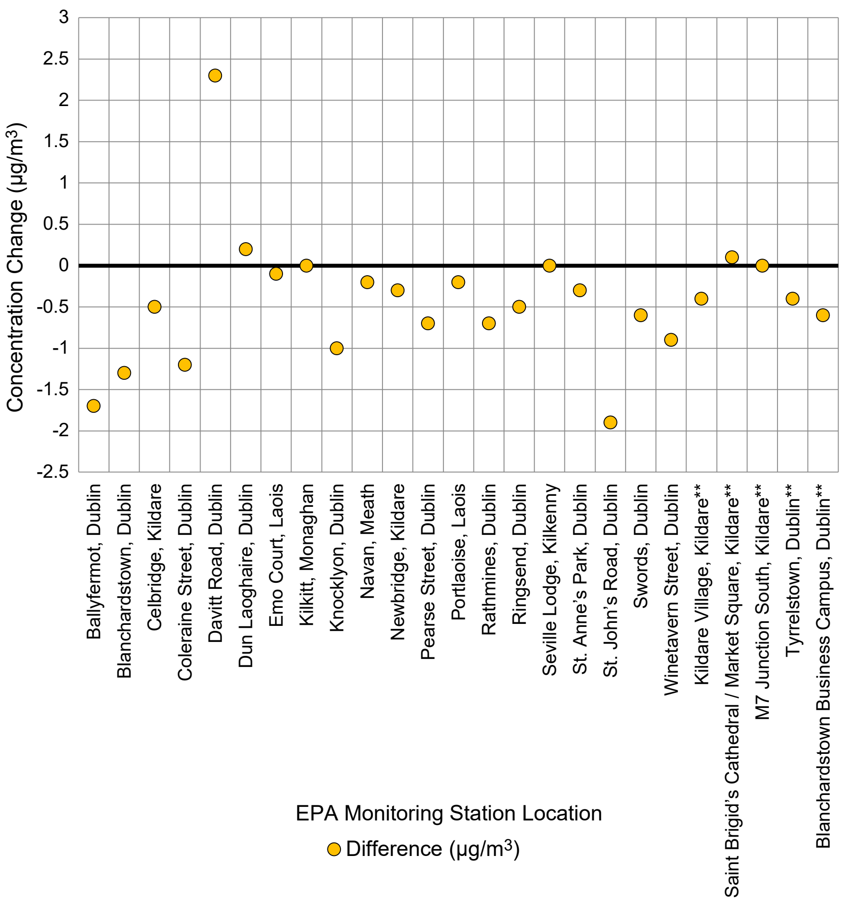

Figure 4.4. Blanchardstown Business Hub relocation: concentration changes at monitoring stations and additional locations. (Additional locations included in the analysis referred to earlier.)**

0.1 to a decrease of 0.6 μg/m^3, highlighting that the relocation of businesses had limited negative impacts in terms of NO_2 concentrations.

The changes in NO_2 concentration in Kildare Town ranged from an increase of 0.1 μg/m^3 to a decrease of 0.4 μg/m^3. The concentration changes showed that the mitigation measure had very little negative effect on pollution levels in Kildare. The WS-LUR model was very useful for this analysis, as the direction from which traffic was travelling was important when calculating concentrations. Some traffic from the north-west, west and south-west, which previously travelled in close proximity to the town, no longer continued east past the town. The new traffic from the north-east, east and south-east did not offset this reduction and therefore the overall distance travelled by vehicles in close proximity and within the town was reduced as a result of the mitigation measure.

4.2.2 Removal of diesel vehicles from the SPSV and LPSV fleets

From 2010 to 2019, the percentage of SPSVs fuelled by diesel, which was already high, increased even further, from 59% in 2010 to 82% in 2019 (Department of Transport, Tourism and Sport, 2011–2020). The LPSV fleet also has a high dependency on diesel fuel, with approximately 99.9% of all LPSVs in every year between 2010 and 2019 being diesel-fuelled vehicles. The remaining vehicles were all registered as petrol-fuelled vehicles, except one that was registered as electric in the 2011 register.

The United Kingdom has introduced all-electric-powered LPSV fleets in numerous cities and is currently extending this to other cities, such as Coventry and Oxford, to improve air quality (Department for Transport, 2021). A number of guidance documents have been published to specify the particular types of vehicles that are acceptable for use as SPSVs in Ireland and set limits on the size and age of the vehicle, and on other factors (NTA, 2020). The current limits on the age of SPSVs provide a basis for determining the potential timeline required for a fleet replacement mitigation measure to be fully implemented (Ó Domhnaill *et al*., 2023).

The Five Cities Demand Management Study[1] highlighted that the city centre areas of four of the five major cities in Ireland have considerably larger percentages of both SPSVs and LPSVs in use compared with the national average. SPSVs make up 0.83% of the national average vehicle fleet, while 8.07%, 2.13%, 1.49%, 2.33% and 0.62% of vehicles within Dublin City, Cork City, Limerick City, Galway City and Waterford City, respectively, are SPSVs. In the national average vehicle fleet, 0.43% of vehicles are LPSVs, while in Dublin City, Cork City, Limerick City, Galway City and Waterford City the percentages are greater than the national average, at 13.43%, 10.64%, 10.32%, 9.32% and 9.94%, respectively.

The aim of the mitigation measure considered here would be to influence the change from diesel to greener fuel options within the SPSV and LPSV fleets (Ó Domhnaill *et al.*, 2023). As a larger proportion of public service vehicles operate in the major cities (Ó Domhnaill *et al.*, 2023), it would be expected that any positive change in terms of the use of newer Euro class vehicles or greener fuel options would lead to a significant improvement in air quality in those areas.

Data

The data used were similar to those used in the previous mitigation strategy, but the focus here was on changes to the vehicle fleet. The pre-mitigation measure scenario represented the national vehicle fleet in 2019 conditions. This vehicle breakdown was then altered to remove diesel-fuelled vehicles from the SPSV and LPSV fleets and replace them with electric-powered vehicles. This change was reflected in small or large changes in the IDWVKT values for different roads, depending on the number of public service vehicles travelling on each road, and consequent changes in modelled NO_2 concentrations in the vicinity of these roads (Ó Domhnaill *et al*., 2023).

Results

Figure 4.5 shows the predicted NO_2 concentration changes at monitoring station locations within Dublin as a result of removing the diesel-fuelled vehicles from the SPSV and LPSV fleets. Overall, this mitigation

1 Department of Transport, Tourism and Sport and SYSTRA, 2020a (five cities), 2020b (Cork), 2020c (Dublin), 2020d (Galway), 2020e (Limerick), 2020f (Waterford).

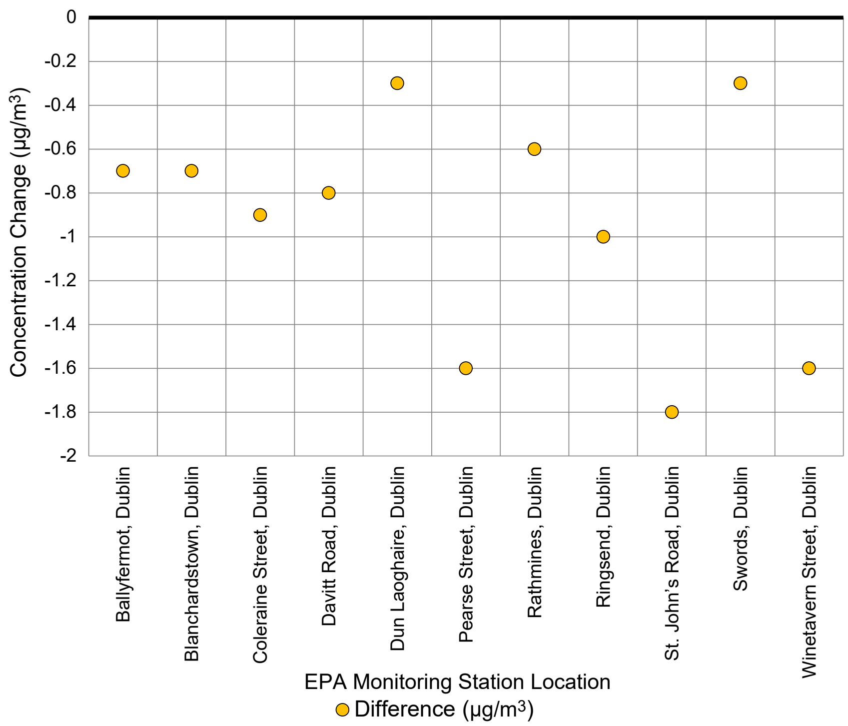

Figure 4.5. Removal of diesel vehicles from the SPSV and LPSV fleets: concentration changes at monitoring stations.

measure produced positive results throughout, with all monitoring stations experiencing reductions in NO_2. The largest reductions in ambient NO_2 concentrations were experienced at monitoring stations within the Canal Corden (Pearse Street, Ringsend, St John's Road and Winetavern Street), where NO_2 reductions ranging from 1.0 to 1.8 µg/m³ were observed (Ó Domhnaill *et al*., 2023). The Five Cities Demand Management Study showed that higher proportions of public service vehicles operate in these areas than the national average (Department of Transport, Tourism and Sport and SYSTRA, 2020a,b; Ó Domhnaill *et al*., 2023). Areas further away from the city centre experienced smaller reductions, in the range of 0.3 and 0.9 µg/m³, in line with the smaller number of public service vehicles in use in rural and suburban locations (Ó Domhnaill *et al*., 2023).

To accommodate the increase in electric vehicles associated with this mitigation measure, a further expansion of the existing charging point network would be required to accommodate the increased demand. A large proportion of the existing charging point network for electric vehicles in Ireland is located in urban districts and city centres (ESB, 2021), which aligns with the expected demand from the public service vehicle fleets.

4.2.3 A bypass route – Cork ring road

Previous studies have suggested the potential to reduce NO_2 concentrations by the provision of a bypass or relief road (Department for Environment, Food & Rural Affairs, 2015; Department for Environment, Food & Rural Affairs and Department for Transport, 2017). Such measures aim to provide alternative routes for road network users, thereby reducing congestion at particular locations and reducing the overall distance travelled by vehicles. In this section, the results of an analysis that investigated the potential of a city bypass/ring road to reduce NO_2 levels are presented.

This analysis considered Cork City and the proposed northern bypass extending from the N22 road at Ballincollig, west of the city, to the M8 junction in the north-east of the city (north of Glanmire).

Data

Traffic flow data for the Cork ring road scenario were based on outputs from the NTA's South Regional Model covering roads of all standards (motorway, national, rural, local, unclassified) within Munster. All EPA monitoring stations located within the confines of the south region of the NTA model were considered in this analysis and a number of additional locations were included. Four additional locations, one at each of the major interchanges between the existing road network and the new Cork ring road (N22/R608 junction, N20 junction, R614 Ballyhooly New/Old Mallow Road junction and the M8 junction), were identified as areas where considerable traffic flow changes could occur close to the new route and existing major routes into the city. This provided the opportunity to identify which routes would contribute to changes in ambient NO_2 concentrations. Another two additional locations (N40 South Ring/N71 Bandon junction and Passage West) were identified as existing corridors into the city.

All other data inputs were similar to those used in the previously described mitigation strategies.

Results

The results cover predicted changes in the flow of each of the vehicle type categories (AADT, car/taxi, LGV, HGV and LPSV) resulting from the introduction of a ring road around the north side of Cork City for every road in the NTA South Regional Model. The results for AADT and LGVs are shown in Figures 4.6 and 4.7. The introduction of a ring road had a positive influence on vehicle flows on the major routes from the north into Cork City, with reductions in AADT of greater than 10% experienced on sections of these major routes (N20, N8/M8, R616/R615/R635 and the R614/Old Mallow Road) on the city side of the ring road and through the city centre, as shown in Figure 4.6. The AADT on the N22/R608 (corridor from the west of Cork), in close proximity to the ring road interchange, increased by over 10%, indicating that traffic previously passing through the city from the north and east to cross the River Lee could now use the ring road to travel to locations in Ballincollig and the west of the city. Similar trends were experienced in the car/taxi flows.

A different trend was experienced in the LGV fleet on some of the major routes (N20 and M8) into the city, with the flows increasing by 10% on sections on the city side of the ring road, as shown in Figure 4.7. Minor reductions in HGV traffic flows were experienced on the majority of routes inside the ring road, while major routes such as the N20, M8/N8 and N40 South Link

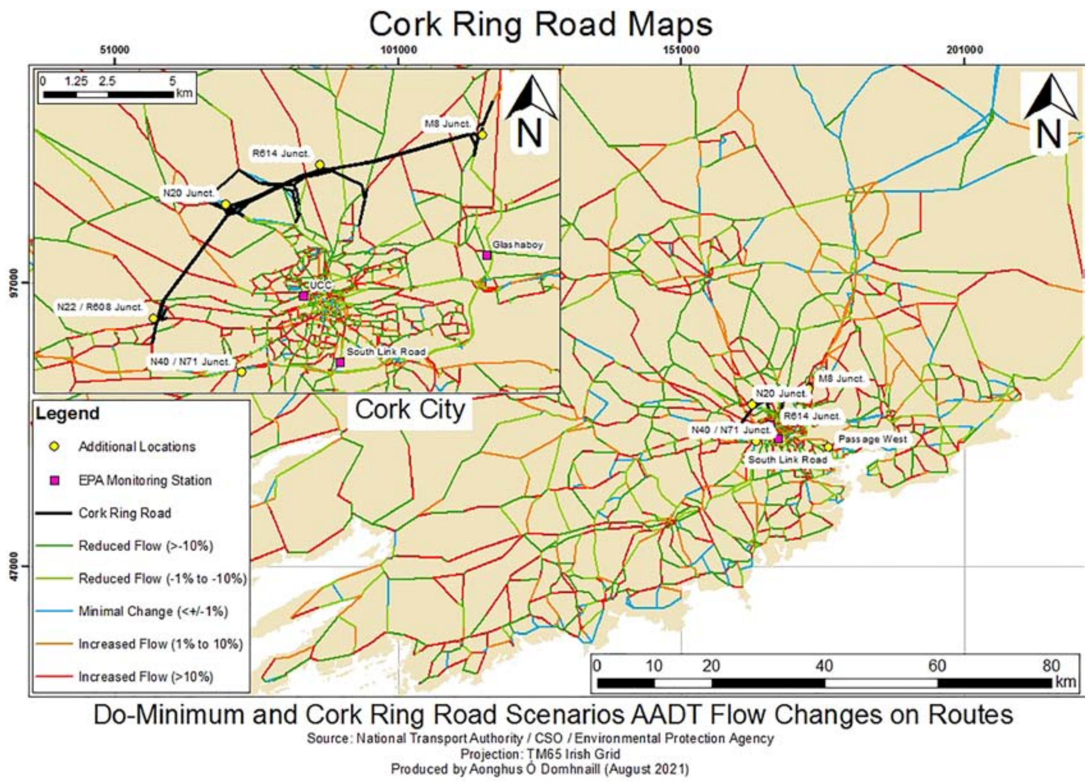

Figure 4.6. Cork ring road and do-minimum scenarios: AADT flow changes on routes. Data sources: Central Statistics Office, Ireland, licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/); NTA, Ireland, permission granted; © Tailte Éireann/Government of Ireland, Copyright Permit No. MP 003023.

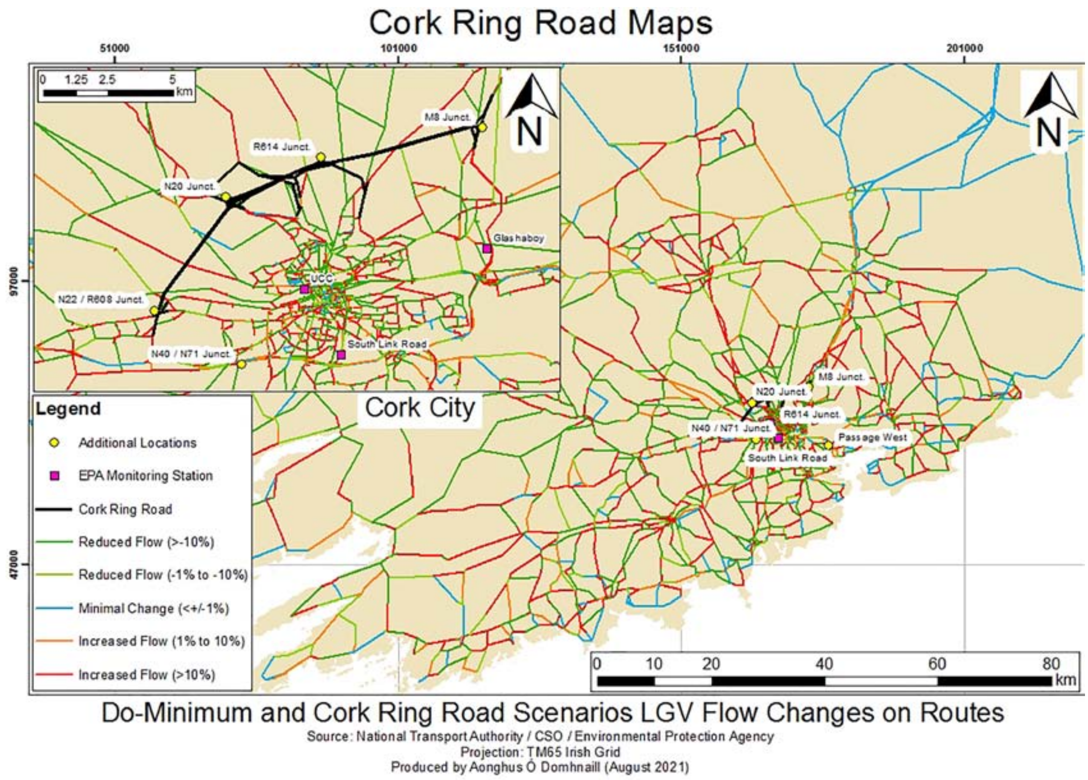

Figure 4.7. Cork ring road and do-minimum scenarios: LGV flow changes on routes. Data sources: Central Statistics Office, Ireland, licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/); NTA, Ireland, permission granted; © Tailte Éireann/Government of Ireland, Copyright Permit No. MP 003023.

Road experienced reductions of greater than 10% in HGV flows as a result of vehicles using the new ring road to travel from one side of the city to the other. Changes in the LPSV flows were largely unaffected by the introduction of the ring road.

Figure 4.8 shows the predicted NO_2 concentration changes at the EPA monitoring station locations in Cork City and the additional locations described above. Minimal change was experienced at the Glashaboy station, while a small increase of 0.2 µg/m^3 in ambient NO_2 concentration was experienced at the University College Cork station. A decrease of 0.4 µg/m^3 was experienced at the South Link Road station associated with changes in local traffic flows, particularly along the South Link Road. As expected, the ambient NO_2 concentrations at the N22/R608 junction, N20 junction and R614/Old Mallow Road junction locations in close proximity to the ring road increased, by 2.5 µg/m^3, 1.8 µg/m^3 and 3.6 µg/m^3, respectively, as a result of the additional flows along the ring road. These increases occurred in locations with relatively low modelled concentrations (< 6.5 µg/m^3) in the do-minimum scenario (i.e. before the introduction of the ring road).

The M8 junction location experienced a decrease of 1.3 µg/m^3 in ambient NO_2 concentration as a result of the reduction in traffic travelling southbound through the M8 junction that had previously used the ring road to travel to the south or west of the city. The changes in ambient concentration at the Passage West location were minimal owing to the limited change in traffic at this location, while, despite the major increase in traffic north of the N40/N71 junction location, the ambient NO_2 concentration increased by only 0.1 µg/m^3.

4.2.4 A low-emission zone in Dublin

The implementation of an LEZ in London was observed to have a considerable impact on vehicle fleet composition, with increased rates of vehicle upgrades from older Euro classes to newer Euro classes with lower emissions (Ellison *et al*., 2013). It was highlighted that the LEZ did not have an impact on flows of certain vehicle types, such as goods vehicles, but did have a positive effect on the replacement of older vehicles with vehicles from these categories. Increased upgrade rates were also noticed in the years

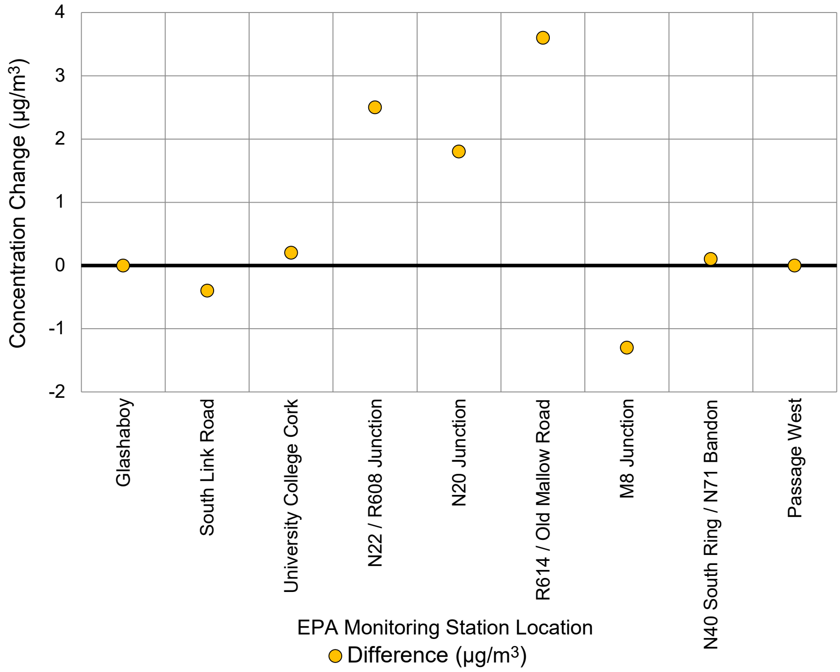

Figure 4.8. Cork ring road and do-minimum scenarios: concentration changes at monitoring stations.

before the implementation of the LEZ, highlighting the positive impact that the planning of these mitigation measures could have on public attitudes and the vehicle fleet composition.

The introduction of a congestion charge/LEZ zone and planning around which vehicle types are exempt from the charge can have a substantial impact on vehicle selection by the population when upgrading vehicles. The exemption of hybrid electric vehicles from the congestion charge resulted in a substantial increase in hybrid electric vehicles in the following years (Morton *et al.*, 2017). The introduction of an "ultra" LEZ in London further reduced average NO_2 concentrations at the beginning of 2020 (Greater London Authority, 2021).

The aim of the mitigation measure presented in this section was to quantify the changes in ambient NO_2 concentrations that would result if a congestion charge/LEZ scenario was implemented in Dublin. Modelling was conducted using the NTA model. The charge to enter the zone, shown in Figure 4.9, is €10.00. The charge was not applied to any vehicle whose trips originated in the zone.

Data

Traffic flow data for the Dublin LEZ/congestion charge scenario were based on outputs from the NTA's East Regional Model, which contains roads of all standards (motorway, national, rural, local, unclassified) within Leinster. The model was developed for a future year (2030) and therefore includes growth rates for future traffic flows compared with the 2019 modelled flows (Transport Infrastructure Ireland, 2021). All EPA monitoring stations located within the confines of the east region of the NTA model were considered in this analysis.

The IDWVKT values were reduced in the majority of sectors around the EPA monitoring stations within Dublin. As traffic demand is expected to generally increase between 2019 and 2030, these modelled reductions in IDWVKT values suggest that the congestion charge/LEZ has the potential to negate this increased demand and even reduce overall IDWVKT values at some locations. The IDWVKT statistics were largely unchanged for the EPA monitoring stations outside Dublin. There are a number of reasons for this, including trips in these locations not being affected by the congestion charge/LEZ, as the origin/destination of the trips are not in Dublin city centre, and the transport options for travel to Dublin city centre from these locations being limited and transport choice therefore remaining largely unchanged.

The other data used in the analysis were similar to those used previously in the other mitigation strategies for the year 2019.

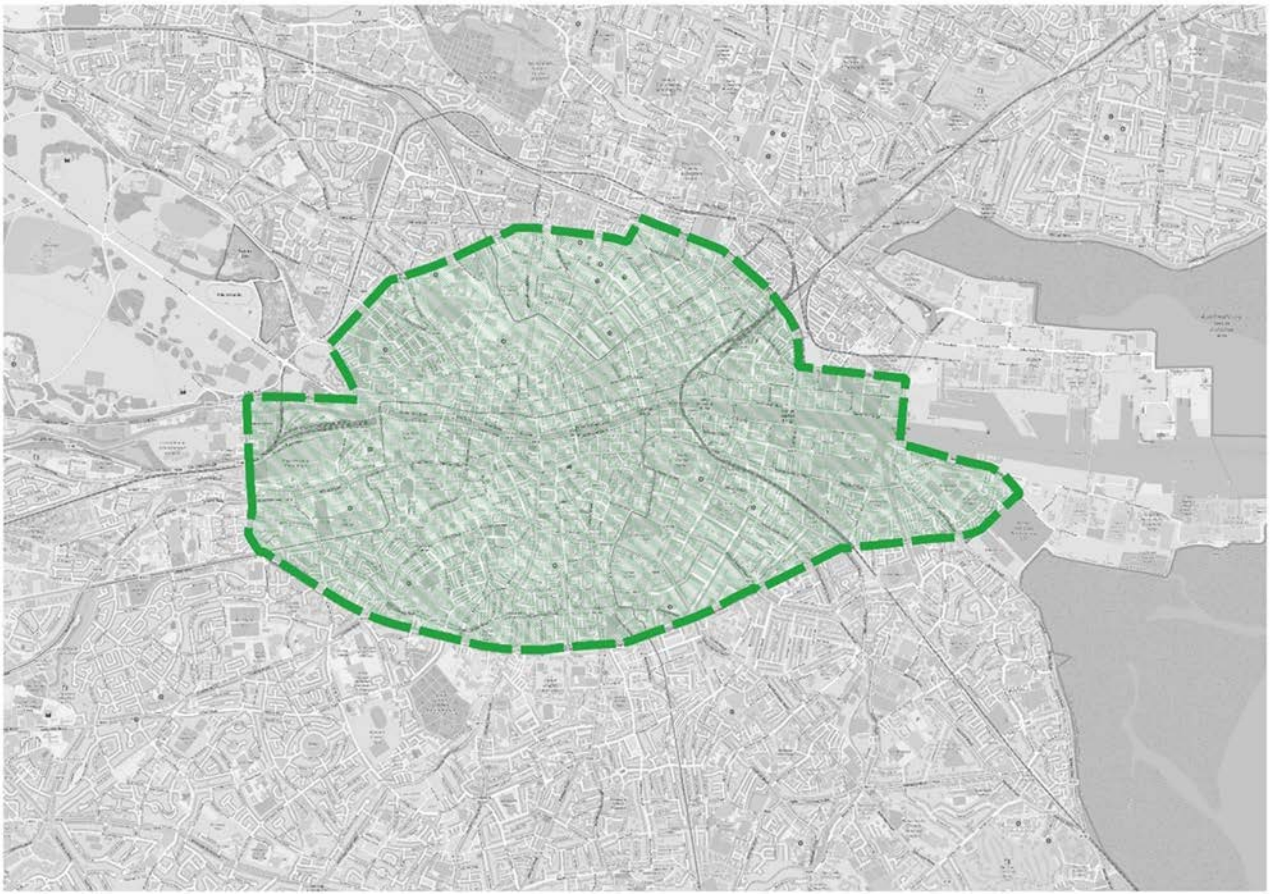

Figure 4.9. Dublin LEZ/congestion charge boundary based on East Regional Model. Source: NTA, 2020 (used with permission from the National Transport Authority, Ireland).

Results

The results focus on the predicted flow changes in each of the vehicle type categories (AADT, car/taxi, LGV, HGV and LPSV) for every route in the NTA East Regional Model following the introduction of the congestion charge/LEZ charge for entry to the Dublin city centre area. The changes in AADT and LGV flows are shown in Figures 4.10 and 4.11. Modelling a do-minimum scenario shows that the modelled flows of LGVs within Dublin could be approximately 20% greater in 2030 than in 2019, and approximately 40% greater for HGVs (Transport Infrastructure Ireland, 2021). Therefore, the changes in modelled flows include both the increase in traffic flows for a future year as well as any changes in a future year resulting from the implementation of the LEZ/congestion charge.

The AADT flows predicted on major routes (such as the M1 (Belfast), M3 (Cavan), M4/M6 (Sligo/Galway), M7 (Limerick) and M50) for 2030 with the LEZ/congestion charge are > 10% lower than the 2019 AADT flows, as shown in Figure 4.10. As the majority of vehicles on routes are cars/taxis, this change is reflected in the car/taxi flows. However, Figure 4.11 shows increases of > 10% in LGV flows on a significant proportion of routes. There could be a number of reasons for this, including the expected increase in traffic flow in future years, and the probability that commercial vehicle trips will be less affected by LEZs/congestion charges, as they are more likely to be work related (deliveries, etc.) and therefore allowed to enter the zone without paying the charge.

Increases of > 10% in HGV flows were experienced on the M50, the main corridors from the M50 into Dublin city centre, the Dublin Port Tunnel and routes along the quays in Dublin City, despite the implementation of an LEZ/congestion charge. The scale of the increases could be affected by the comparison with a future year but the LEZ/congestion charge would not have a major impact on the HGV fleet (trucks and goods vehicles exceeding 3.5 tonnes), as these vehicles would need to travel through the city centre area to service Dublin Port. The LPSV flows were largely unaffected outside

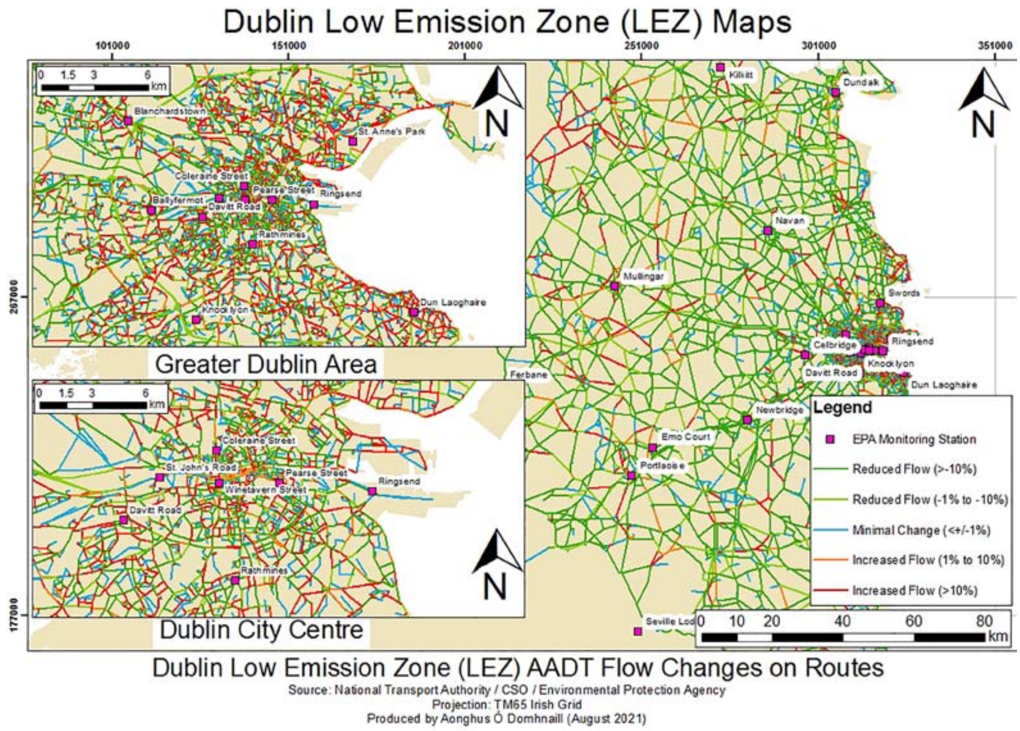

Figure 4.10. Dublin LEZ/congestion charge scenario: AADT flow changes on routes. Data sources: Central Statistics Office, Ireland, licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/); NTA, Ireland, permission granted; © Tailte Éireann/Government of Ireland, Copyright Permit No. MP 003023.

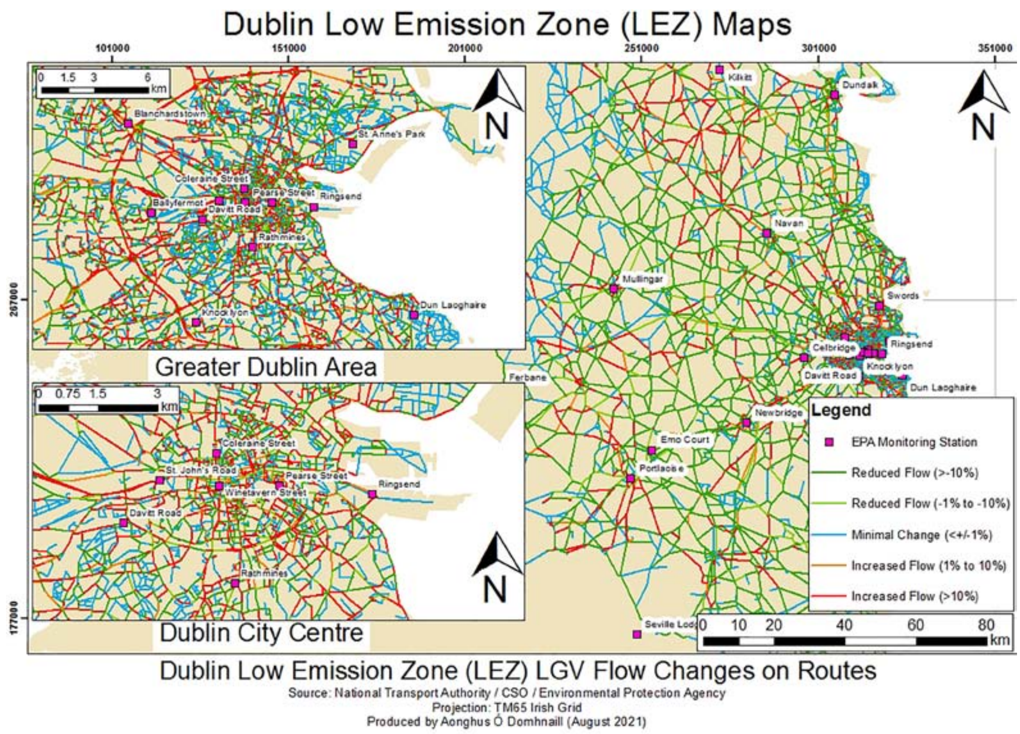

Figure 4.11. Dublin LEZ/congestion charge scenario: LGV flow changes on routes. Data sources: Central Statistics Office, Ireland, licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/); NTA, Ireland, permission granted; © Tailte Éireann/Government of Ireland, Copyright Permit No. MP 003023.

the M50, with increases and decreases in the range of only 10 to 100 vehicles per day on the M3, M4/M6 and M7 major routes. In the Greater Dublin Area (within the M50 route), a number of main corridors into the city centre experienced increases of greater than 100 LPSVs per day. This is likely to be the result of the combined effects of the predicted increases in future year flows and the greater popularity of LPSVs following the introduction of the congestion charge.

Figure 4.12 shows the predicted changes in modelled concentrations at the EPA monitoring station locations due to the introduction of a congestion charge/LEZ in the Dublin city centre region. All of the city centre monitoring station locations – Coleraine Street, Pearse Street, Ringsend, St John's Road and Winetavern Street – display significant decreases in ambient NO_2 concentrations, of 1.9, 1.6, 1.2, 3.0 and 2.1 µg/m^3, respectively. These reductions were mainly due to the substantial reductions in IDWVKT values associated with reduced flows.

4.2.5 *Impact of COVID-19 lockdown on nitrogen dioxide levels*

In addition to the mitigation strategy analyses described above, the improved WS-LUR model was also used to assess the impact of the first COVID-19 lockdown on NO_2 levels. The objectives were to:

- evaluate the capability of the WS-LUR model to calculate changes in ambient NO_2 concentrations for unique scenarios;
- model NO_2 concentrations at various locations during the first COVID-19 lockdown period (28 March 2020 to 17 May 2020);
- characterise the meteorological, source location and traffic conditions during the first COVID-19 lockdown period;
- based on the performance of the model in this scenario, identify the effect of individual parameter changes experienced during the COVID-19 lockdown on ambient NO_2 concentrations and the potential NO_2 reductions that could be achieved by mitigation measures that target these parameters (Ó Domhnaill *et al*., 2023).

Comparison of measured and modelled COVID-19 lockdown concentrations

In Figure 4.13, the modelled concentrations for the first COVID-19 lockdown period are compared with measured concentrations at various EPA monitoring locations. As can be seen, the modelled

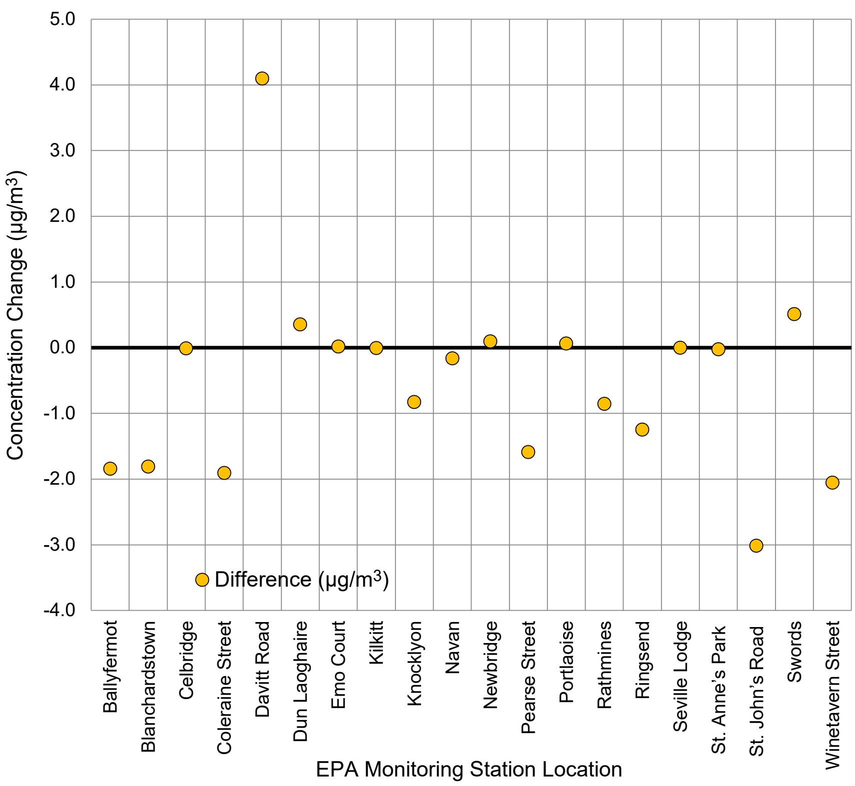

Figure 4.12. Dublin LEZ/congestion charge scenario: concentration changes at monitoring stations.

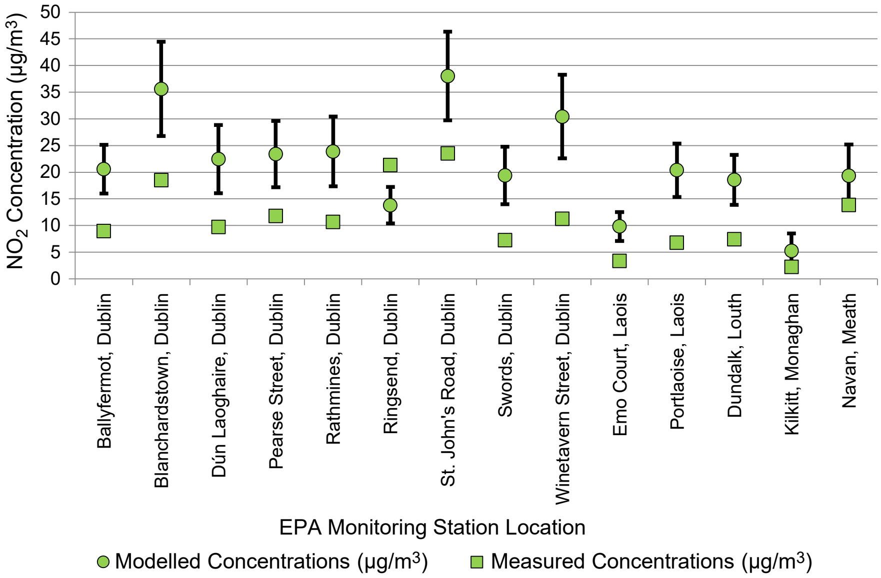

Figure 4.13. COVID-19 lockdown: measured and modelled concentrations with standard error bars.

results compare reasonably well with the measured concentrations from the Kilkitt monitoring station in Monaghan, a rural location. However, similar to the results of the 2016–2018 analyses presented in Appendix 1, the model overestimated the concentrations at all other stations except the Ringsend monitoring station in Dublin, where the model underestimated the concentration by approximately 4.4 µg/m³. The Ringsend result was similar to the results achieved in the analysis using the original model, which also underestimated measured NO_2 concentrations. Other factors that are not captured by the model's predictor variables could have influenced this outcome for Ringsend, such as emissions from traffic and shipping within Dublin Port or from an industrialised area in close proximity to the monitoring station site.

The original model captured 78% of the spatial variability in NO_2 with a cross-validation coefficient of determination (R^2) of 77.4% (Naughton *et al.*, 2018; Ó Domhnaill *et al.*, 2023). The cross-validation R^2 was significantly lower for the first COVID-19 lockdown period, at 44.03%, and was strongly influenced by the measurement at Ringsend, Dublin. The cross-validation R^2 improves considerably, to 82.27%, when the outlier at Ringsend is excluded.

Comparison of pre-COVID-19 and COVID-19 lockdown concentrations

The modelled concentrations display greater differences between the pre-COVID-19 and COVID-19 scenarios than are observed in the measured concentrations, as shown in Figure 4.14 (Ó Domhnaill *et al.*, 2023). The overestimation of the change in concentrations at the majority of stations could be due to a number of factors relating to the unique conditions being examined (Ó Domhnaill *et al.*, 2023).

The commercial properties predictor variable mainly reflects the number of commercial properties surrounding a study location, but an unknown proportion of this variable captures the effects of the other variables, such as residential property numbers, which were not included as independent predictor variables, as they did not satisfy the selection conditions (Ó Domhnaill *et al.*, 2023). Therefore, for the COVID-19 analysis, the modelled reduction in commercial properties should be less than the full reduction experienced during the lockdown period to allow for the enduring implicit contributions of other influences such as residential property numbers (Ó Domhnaill *et al.*, 2023). This would lead to smaller differences between modelled pre-COVID-19 lockdown concentrations and modelled COVID-19 lockdown concentrations, particularly in more urban environments (Ó Domhnaill *et al.*, 2023).

Considering the temporary nature of the conditions being examined, it is relevant that during the COVID-19 lockdown period weather conditions were significantly different from those experienced during the model calibration period and in the earlier study years of 2016–2018 (Ó Domhnaill *et al.*, 2023). The predominant wind direction during the

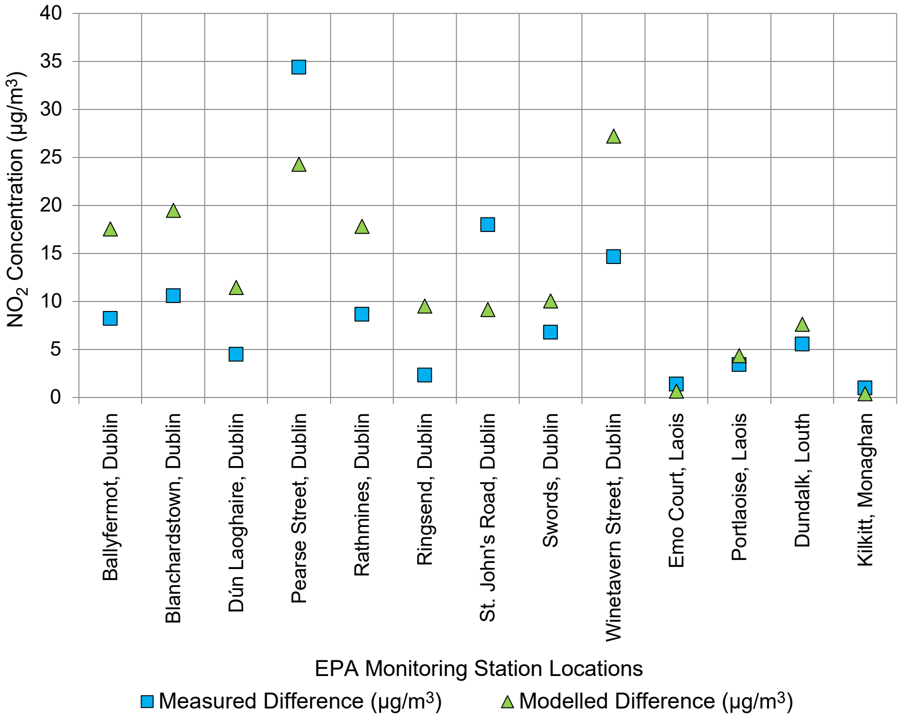

Figure 4.14. Measured and modelled differences between pre-COVID-19 and COVID-19 lockdown scenarios.

lockdown period was easterly, whereas during the other periods (including the pre-COVID-19 period) the predominant wind direction was westerly/south-westerly (Ó Domhnaill *et al*., 2023). A predominant westerly/south-westerly wind would bring fresh air in from the Atlantic Ocean, whereas an easterly wind direction would transport air from continental Europe and the United Kingdom, which could contain higher concentrations of pollutants (Donnelly *et al*., 2019; Ó Domhnaill *et al*., 2023). As a consequence, the measured reductions in concentrations during the lockdown period are likely to have been smaller than would have been experienced with annual average wind directions (Ó Domhnaill *et al*., 2023). This indicates that the full impact of reduced local emissions is not evident in the measured difference values shown in Figure 4.14 owing to a concurrent increase in background concentrations (Ó Domhnaill *et al*., 2023).

The WS-LUR model is not able to capture the effect of atypical, short-term meteorological conditions on average background concentrations (Ó Domhnaill *et al*., 2023). An increase in background concentrations should be reflected in a greater value for the constant within the ambient NO_2 concentration model, but the calibration process provides just a single annual average value that is applied uniformly across the entire country (Ó Domhnaill *et al*., 2023). On the other hand, the WS-LUR model did capture the effects of the COVID-19 lockdown period wind directions on the predictor variables within the model, as these were weighted based on the wind direction proportions experienced during the particular study period being analysed (Ó Domhnaill *et al*., 2023).

5 Conclusions and Recommendations

5.1 Conclusions

To investigate the impact of NO_2 on health, two separate analyses were performed as part of the project work programme. The first was an analysis to determine if associations exist between the rates of prescribing respiratory medicines and $PM_{2.5}$ and NO_2 levels. The prescription data were obtained from GMS (medical card) data on dispensing from September 2014 to December 2016 for four LHOs. The air pollution data were obtained from contemporary data measured at EPA air quality monitoring stations either in the region or, in the case where a monitor was not available in the region, from a similar location type. The conclusions from this analysis are as follows:

- Winter was the variable with the strongest association with prescription dispensing outcomes, and this was most pronounced in the analyses undertaken in the 0–4 years age category.
- For most of the outcomes investigated, there was no association evident between the levels of NO_2 and the outcomes of interest.
- In most regions, there was an association between $PM_{2.5}$ and the outcomes of interest, taking account of the impact of winter on dispensing. This was most pronounced with oral steroids and especially in the subgroup analyses undertaken in the 0–4 years age group.

The second analysis (Carthy *et al*., 2020) using health data focused on the TILDA database, which hosts health data and other socio-economic data of 8162 adults aged 50+ in Ireland (Kearney *et al*., 2011; Donoghue *et al*., 2018). The analysis was completed in collaboration with ESRI. The TILDA data were used to determine if associations exist between estimated NO_2 levels in the area where the database participants reside and their health, using the model developed in Naughton *et al*. (2018). The conclusions from this analysis are as follows:

- The results of the analysis of the effect of NO_2 levels on the health of older adults demonstrated a strong positive association with asthma prevalence.
- The results from model 1 (asthma self-reports) suggest that a 1 ppb increase in NO_2 concentration is associated with a 0.24 percentage point increase in the probability of reporting an asthma diagnosis for those exposed to levels of < 13.1 ppb.
- For those living in areas exposed to levels higher than 13.1 ppb, there was an effect size of an order of magnitude higher, but also a larger standard error. In the case of model 2 (medications), a 1 ppb increase in NO_2 concentration was associated with a 0.26 percentage point increase in the probability of requiring medication for asthma.
- The magnitude of association is large for both models. Associations between local air pollution and asthma among older adults were found even at relatively low concentrations.

Having examined the impacts of NO_2 on health, the research moved to examining potential mitigation strategies to reduce NO_2 levels. Ambient NO_2 concentrations at various locations throughout Ireland were calculated using combined LUR-based air quality modelling and transport modelling. An enhanced WS-LUR model for calculating ambient NO_2 concentrations was developed based on previous work by Naughton *et al*. (2018). The model was used to evaluate a number of mitigation measures to reduce NO_2 levels. The following conclusions were drawn.

The first mitigation strategy, the relocation of businesses in Blanchardstown to Kildare, resulted in the following:

- A positive influence on vehicle flows on the major (national and motorway) routes into Dublin was seen, with reductions of up to 10% in AADT on the majority of route sections. Motorway routes experienced reductions in the range of 1–10% in car/taxi flows, more than a 10% reduction in LGVs and reductions of greater than 100 vehicles per day in the HGV and LPSV categories.
- Significant reductions in NO_2 in the Dublin city centre locations, ranging from 0.5 to 1.9 $\mu g/m^3$, were seen. The Dún Laoghaire and Davitt Road

monitoring station locations, outside Dublin city centre, experienced increases of 0.2 and 2.3 μg/m^3, respectively, which was mainly the result of the substantial increases in IDWVKT occurring in the predominant west and south-west wind direction sectors. In close proximity to the original business locations (i.e. at the Blanchardstown EPA monitoring station and the Tyrrelstown and Blanchardstown Business Campus additional locations), the NO_2 reductions ranged from 0.4 to 1.3 μg/m^3.

As expected, owing to the increased job attractions within the Kildare Town region, flows on routes towards the town increased by more than 10% in the AADT, car/taxi and LGV vehicle categories, and the number of HGVs and LPSVs on routes towards Kildare Town also increased by more than 100 vehicles per day. The changes in NO_2 concentration in Kildare Town ranged from an increase of 0.1 μg/m^3 to a decrease of 0.4 μg/m^3. Traffic from the north-west, west and south-west that previously travelled in close proximity to the town no longer continued east past the town, and the new traffic from the north-east, east and south-east did not offset this reduction.

The second mitigation strategy modelled was the removal of diesel vehicles from the SPSV and LPSV fleets. The following conclusion is drawn from the analysis:

- Overall, this mitigation measure improved air quality, with all monitoring stations experiencing reductions in NO_2. The largest reductions in ambient NO_2 concentrations were experienced at monitoring stations within the Canal Corden (Pearse Street, Ringsend, St John's Road and Winetavern Street), where the proportions of SPSVs and LPSVs are significantly above the national average (Ó Domhnaill *et al*., 2023). The observed reductions ranged from 1.0 to 1.8 μg/m^3. Rural and suburban areas further away from the city centre, with fewer public service vehicles, experienced smaller reductions, in the range of 0.3 and 0.9 μg/m^3.

The third mitigation strategy examined was the potential of a city bypass, in this case one to the north of Cork, to reduce NO_2 levels. This analysis showed that air quality changes depended on the effect of the new route on traffic flow at different locations around Cork. The conclusions are as follows:

- The introduction of a ring road around the north side of Cork City reduced vehicle flows on the major routes into Cork City from the north, with reductions in AADT greater than 10% experienced on sections of the major routes (N20, N8/M8, R616/R615/R635 and the R614/Old Mallow Road) on the city side of the ring road and through the city centre. In contrast, AADT on the N22/R608 (corridor from the west of Cork), in close proximity to the ring road interchange, increased by over 10%. A different trend was displayed in the LGV flows on some of the major routes (N20 and M8) into the city, with flows increasing by 10% on sections of these routes on the city side of the ring road.
- Minimal change in NO_2 levels was modelled at the location of the Glashaboy monitoring station, while an increase of 0.2 μg/m^3 in ambient NO_2 concentration was experienced at the University College Cork station location. A decrease of 0.4 μg/m^3 was experienced at the South Link Road station; the change in traffic flows, particularly along the South Link Road, was the main cause of this reduction. As expected, ambient NO_2 concentrations at the N22/R608 junction, N20 junction and R614/Old Mallow Road junction locations in close proximity to the ring road increased, by 2.5 μg/m^3, 1.8 μg/m^3 and 3.6 μg/m^3, respectively.

The fourth mitigation strategy analysed was the introduction of an LEZ in Dublin. This was modelled by means of an LEZ/congestion charge on vehicles entering the city. The conclusions are as follows:

- Modelling for a do-minimum scenario showed that predicted future traffic flows within Dublin in 2030 would increase above modelled flows for 2019 by approximately 20% for LGVs and approximately 40% for HGVs (Transport Infrastructure Ireland, 2021). The modelled changes in traffic flow used to predict the air quality benefits of the mitigation measure therefore include both the general increases in traffic flows expected for future years and the effect of the implementation of the LEZ/congestion charge.

- All of the city centre monitoring station locations – Coleraine Street, Pearse Street, Ringsend, St John's Road and Winetavern Street – experienced substantial decreases in ambient NO_2 concentrations, of 1.9, 1.6, 1.2, 3.0 and 2.1 μg/m^3, respectively. These reductions, which were mainly due to substantial decreases in IDWVKT in the predominant wind direction sectors, are significant in the context of the EU limit value of 40 μg/m^3, which has previously been exceeded at Dublin city centre locations.

In addition to the mitigation strategies, an analysis modelling the impact of the first COVID-19 lockdown was also included in the project work programme. The conclusion of this analysis is as follows:

- Modelled concentrations of NO_2 for the first COVID-19 lockdown period were compared with measured concentrations at various EPA monitoring locations. The modelled results compared reasonably well with the measured concentrations at the Kilkitt monitoring station in Monaghan, a rural location. However, the model overestimated the concentrations at all other stations except the Ringsend monitoring station in Dublin, where the model underestimated the concentration by approximately 4.4 μg/m^3. Location-specific factors not captured by the model may have contributed to this underestimation, such as boat traffic entering and leaving Dublin Port, vehicular/machinery traffic working in the port and the proximity to electricity-generating stations at Poolbeg.

5.2 Recommendations

Based on the results of the project, the following eight recommendations are made:

1. Initial investigations carried out as part of the project concluded that access to available health datasets by researchers is extremely limited and this is reducing the potential to study the impacts of air pollution on health. The main barriers include lack of coordinated data sharing and privacy concerns. It is recommended that policies and protocols be developed to enable researchers to access existing health data without compromising privacy. The associated benefit to society, as demonstrated by the findings of this project in relation to asthma and prescribing rates, could be substantial.
2. The results of the respiratory item prescribing rate analysis using the HSE-PCRS database did not suggest any association between NO_2 levels and prescribing rates. Although it was not an objective of the project, the research team had the opportunity to consider $PM_{2.5}$ levels as well as NO_2 levels in this analysis. The results of this analysis demonstrated a strong positive association between $PM_{2.5}$ and prescribing rates, particularly in young children. It is therefore recommended that current efforts seeking to improve air quality nationally be intensified.
3. The results of the analysis of the effect of NO_2 levels on the health of older adults demonstrated a strong positive association with asthma prevalence. These results lend support to the view that measures to reduce NO_2 can make a significant contribution to health.
4. The enhanced WS-LUR model featuring detailed local traffic fleet composition modelling offers a robust and efficient method to evaluate the effects of mitigation strategies on NO_2 levels. It is recommended that it is used in transport policy development to supplement existing modelling tools.
5. The mitigation strategy analyses showed how a range of possible traffic management and infrastructure measures could reduce overall NO_2 levels. Based on these findings, it is recommended that resources and policy development are focused on developing incentives to reduce car use, and on promoting and adequately resourcing public transport and active transport modes in line with existing policy frameworks and strategies, including existing support for electric vehicles, SPSVs and alternatively fuelled HGVs, and with the Programme for Government and revised National Development Plan commitments to increase spending on public transport and active travel. The results obtained in the mitigation strategy analyses demonstrate that modelling can be used to support decision-making by quantifying the potential reductions in NO_2 that are likely to be achieved by alternative plans.

6. The analysis of the impacts of the first COVID-19 lockdown demonstrated the potential air quality benefits of working-from-home policies. Homeworking has the potential to contribute significantly to improving air quality. It should be noted that the research did not analyse how increases in home heating requirements as a result of homeworking affected air quality.
7. The results of the mitigation strategy analyses showed that all strategies offered the potential to reduce NO_2 levels. In absolute concentration reduction terms, none of the investigated strategies is indicated as being more successful than the others, with a maximum improvement in annual average NO_2 concentration of approximately 2 $\mu g/m^3$ being predicted in each case. Greater concentration reductions could be achieved by implementing multiple strategies together. However, in the context of achieving reductions in the short to medium term, some strategies can be more readily implemented than others. They include the replacement of diesel vehicles by electric vehicles in the SPSV and LPSV fleets and the relocation of businesses away from areas with high air pollution levels.
8. Data from the EPA air pollution monitoring system were instrumental in the delivery of this project. It is recommended that this system be resourced further and expanded because of its fundamental importance in air pollution research (including in the development of nationally relevant air quality models) and information provision to the public. Nationally, the number of locations where $PM_{2.5}$ concentrations are monitored is currently greater than the number where NO_2 concentrations are monitored. Additional NO_2 monitoring in urban areas would provide better information about individual and population exposure and allow more accurate air quality model development and validation. Additional NO_2 monitoring in rural areas would also support model development, especially in terms of the representation of background concentrations and investigating the influence of transboundary pollution. Monitoring at coastal locations, such as those where ozone monitoring is currently being performed and on the eastern seaboard, could provide valuable information in this regard.

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Abbreviations

AADT	Annual average daily traffic
CI	Confidence interval
CORINE	Coordination of Information on the Environment
COVID-19	Coronavirus disease 2019
EEA	European Environment Agency
EPA	Environmental Protection Agency
ESRI	Economic and Social Research Institute
GIS	Geographic information system
GMS	General Medical Services
HDV	Heavy-duty vehicle
HGV	Heavy goods vehicle
HSE-PCRS	Health Service Executive Primary Care Reimbursement Service
IDWVKT	Inverse distance-weighted vehicle kilometres travelled
ISA	Integrated Science Assessment
LCV	Light commercial vehicle
LEZ	Low-emission zone
LGV	Light goods vehicle
LHO	Local health office
LPSV	Large public service vehicle
LUR	Land use regression
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
NTA	National Transport Authority
PCU	Passenger car unit
$PM_{2.5}$	Particulate matter consisting of particles with a diameter of 2.5 microns or less
ppb	Parts per billion
R^2	Coefficient of determination
SPSV	Small public service vehicle
TILDA	The Irish Longitudinal Study on Ageing
WHO	World Health Organization
WS-LUR	Wind sector land use regression

Appendix 1 Land Use Regression Model Development

Land use regression (LUR) models use statistical relationships between air quality at a location and the emission sources in the vicinity (Ó Domhnaill *et al*., 2023). The emission sources can be specific sources, such as individual roads or commercial facilities, but generally they are grouped together depending on the predominant land use in an area, e.g. residential, industrial, agricultural, hence the name 'land use regression' (Ó Domhnaill *et al*., 2023). LUR models are calibrated using historical pollution concentration measurements and data on the land uses and other emission sources around the monitoring site (Ó Domhnaill *et al*., 2023). Meteorological conditions are also usually taken into account (Ó Domhnaill *et al*., 2023). If sufficient data are available, a well-developed LUR model can capture all of the parameters that, on average, statistically influence the ambient concentrations of pollutants in a city, region or country (Ó Domhnaill *et al*., 2023). LUR models can be used to calculate pollution concentrations at locations where monitoring has not been carried out and to develop air quality maps, so long as the required input data are available (Ó Domhnaill *et al*., 2023). They can also be employed in scenario analyses to model the effect on air quality of future changes in land uses or emission sources (Ó Domhnaill *et al*., 2023). In this project, nationwide LUR model input data have been compiled for three pre-set years, 2016, 2017 and 2018, allowing users to predict the average annual NO_2 concentration at any location in any of those years (Ó Domhnaill *et al*., 2023). Traffic data are based on modelled data (NTA model outputs) whereas data for the other variables (meteorological, commercial properties and land use) are all actual measurements (Ó Domhnaill *et al*., 2023). The model also includes a manual entry option that allows the user to calculate the average NO_2 concentration at any location for a year outside the pre-set years, including future years (Ó Domhnaill *et al*., 2023).

A1.1 Wind Sector-based LUR Modelling

A1.1.1 Original model

The original methodology used in Naughton *et al*. (2018) calculates NO_2 concentrations using a wind sector land use regression (WS-LUR) model (Ó Domhnaill *et al*., 2023). Wind sector-based regression was found to be the best option for modelling air pollution concentrations in areas with a complex spatial distribution of sources and where the prevailing wind direction varies considerably (Ó Domhnaill *et al*., 2023). The calibration of the method is based on analysis of mean concentrations measured at each of the EPA ambient air quality monitoring sites. This involves (1) categorising the measured hourly concentrations by wind direction using eight sectors and (2) factoring the measured concentration values to reduce seasonal and diurnal bias in each sector arising because of the tendency of concentrations to be higher during winter months and at certain times of the day. This approach substantially increases the amount of fixed-site monitoring data available for model calibration. The position of different sources in the vicinity of the monitoring location is defined by further dividing the eight sectors into eight buffer zones with minimum and maximum sector radii varying between 25 m and 5 km, as shown in Figure A1.1 (Ó Domhnaill *et al*., 2023). This ensures that the proximity of a source to a receptor and its ability to influence concentrations at that receptor is taken into account (Ó Domhnaill *et al*., 2023).

Using this method, the WS-LUR model for the mean concentration at a specific location can be represented as (Naughton *et al*., 2018; Ó Domhnaill *et al*., 2023):

$$C = \alpha_0 + \sum_{i=1}^{8} \sum_{j=1}^{M} Wf_i \, \alpha_j \, P_{ji} \qquad \text{(A1.1)}$$

where C is the modelled pollutant concentration, P_{ji} ($j = 1$,M) are the values of the M selected predictor variables in sector i ($i = 1,8$), α_j are the corresponding regression coefficients and Wf_i is the fraction of hourly wind directors within sector i ($i = 1,8$) (Ó Domhnaill *et al*., 2023).

Data were gathered for a large number of candidate predictor variables describing local spatial distributions of pollutant sources, with a focus on variables relating to the traffic and background characteristics. These candidate predictor variables were analysed initially to determine if they were correlated with measured NO_2 concentrations. In terms of traffic, the trial source

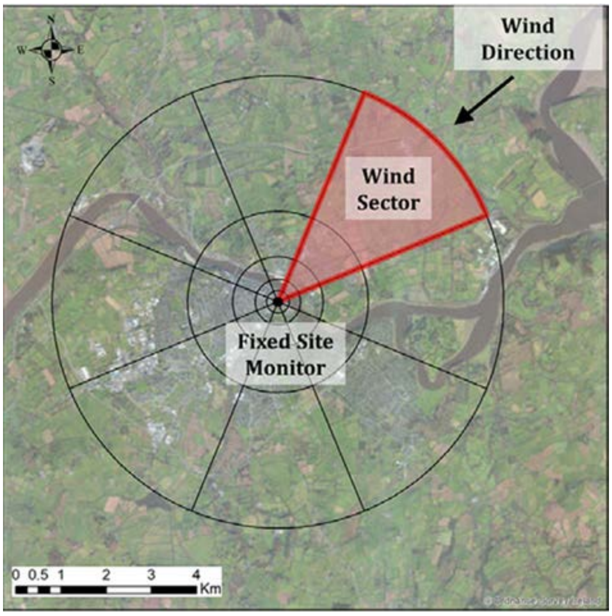

Figure A1.1. WS-LUR wind sectors and buffer zones. Source: reproduced from Naughton *et al.*, 2018, A land use regression model for explaining spatial variation in air pollution levels using a wind sector based approach, *Science of the Total Environment* 630: 1324–1334, https://doi.org/10.1016/j.scitotenv.2018.02.317.

parameters included road length, road proximity and traffic flow. The background variables included land cover type, population density, property density, residential heating, household car ownership and proximity to the coast. The other variables considered included large point source pollutant emissions, elevation and wind speed. A weighting parameter was employed to calculate an inverse distance-weighted traffic flow for each of the buffer radii. Each predictor variable was designated a direction of effect, and a univariate regression analysis was completed on all variables.

The LUR model was created from these variables by adding the highest adjusted coefficient of determination (R^2) variable first, after which the next highest variables were added consecutively to the model and maintained only if (1) the R^2 of the model increased by 1% or more, (2) the direction of effect of the variable was unchanged from the direction of effect from the initial check and (3) the direction of effect of other variables already included in the model did not change (Ó Domhnaill *et al.*, 2023). The variables that produced the highest adjusted R^2 value were included in the final version of model, excluding any variable that had a *p*-value greater than 0.05. The variables that produced the best results were inverse distance-weighted vehicle kilometres in all buffers from 25 m to 5 km radii, the number of commercial buildings within a 1 km radius, the fraction of land that is categorised as agricultural land within a 1 km radius, road density within a 250 m radius and the average wind speed. The data required were obtained from Ordnance Survey Ireland (OSI), Transport Infrastructure Ireland (TII), the National Transport Authority (NTA) and Met Éireann, and data processing and analysis was performed in Microsoft Excel and ArcGIS.

For each wind sector, the inverse distance-weighted vehicle kilometres travelled (*IDWVKT*) predictor variable, P_1, is calculated using:

$$P_1 = IDWVKT = \sum_{b=1}^{B} \frac{1}{d_b} vkm_b \qquad \text{(A1.2)}$$

where vkm_b is the total distance travelled by all vehicles in buffer zone b ($b = 1,B$) and d_b is the radial distance from the monitoring or receptor location to the centre of the buffer zone. The calculation of vkm_b using transport model outputs of annual average daily traffic (AADT) flows is described in the following section (Ó Domhnaill *et al.*, 2023).

A1.1.2 Model improvements

The LUR modelling procedure developed by Naughton *et al.* (2018) was retained, but the capability of the model to capture the effects of vehicle emissions was enhanced (Ó Domhnaill *et al.*, 2023). This involved including additional data describing the national distribution of vehicle characteristics, including vehicle fleet breakdown, Euro classifications and fuel types (Ó Domhnaill *et al.*, 2023). These data have been introduced to further strengthen the model's representation of local measured concentrations and to enable the analysis of mitigation strategies that reduce emissions in specific locations or from specific classes of vehicle (Ó Domhnaill *et al.*, 2023).

The original LUR model developed by Naughton *et al.* (2018) considered only AADT flows within the *IDWVKT* variable, P_1 (Ó Domhnaill *et al.*, 2023). The AADT is the average daily total flow in both directions passing through a point on a route, based on a full calendar year (Transport Infrastructure Ireland, 2016; Ó Domhnaill *et al.*, 2023).

When using AADT flow data, equation A1.2 becomes:

$$P_1 = IDWVKT = \sum_{b=1}^{B} \frac{1}{d_b} \sum_{r=1}^{R} AADT_r, L_r \qquad \text{(A1.3)}$$

where $AADT_r$ is the AADT flow on road link r of length L_r with R road links in buffer zone b (Ó Domhnaill *et al*., 2023). Link-by-link values of AADT flow are available as outputs from transport network models (Ó Domhnaill *et al*., 2023). These AADT flow values include, but usually do not distinguish between, different vehicle types that have considerably different properties, such as engine sizes, vehicle weights and varying levels of emissions (Ó Domhnaill *et al*., 2023). Locations with atypical vehicle type distributions will therefore be less accurately represented within the WS-LUR model (Ó Domhnaill *et al*., 2023). Moreover, over recent decades, vehicle emission standards have led to considerable improvements in vehicle technology that reduces emissions, while transport policies have had major impacts on the fuel type breakdown of the Irish vehicle fleet (EU, 1991; Department of Transport, Tourism and Sport, 2019; Ó Domhnaill *et al*., 2023). Ongoing changes in the vehicle fleet composition since the period when the model was originally developed could gradually become a major weakness when utilising the original regression coefficients in an analysis of future or past time periods outside the original study period, which was between 2010 and 2012 (Ó Domhnaill *et al*., 2023).

To address this issue, the method used to define traffic emission effects in the WS-LUR concentration formula was improved (Ó Domhnaill *et al*., 2023). The improvement involved splitting the AADT element of the *IDWVKT* variable into separate components for each vehicle type (i.e. passenger cars, light goods vehicles (LGVs), heavy-duty vehicles (HDVs), etc.) to allow the application of emission weightings in the *IDWVKT* variable, as follows:

$$AADT_r = \sum_{k=1}^{N} N_{k,r} \qquad \text{(A1.4)}$$

where $N_{k,r}$ is the number of vehicles in category k (Euro class or vehicle type) on road link r (Ó Domhnaill *et al*., 2023).

The emission weighting applied to each vehicle category k is determined by defining a unit reference vehicle with which NO_2 emissions from all vehicle types and Euro classifications could be compared (Ó Domhnaill *et al*., 2023). Since the regression coefficients were based on the original AADT-based *IDWVKT* variable, where all vehicles are considered equal, the reference unit vehicle is a vehicle that emits the average emission for the period being studied (Ó Domhnaill *et al*., 2023). The emission weighting of each vehicle type/Euro classification is defined relative to this reference unit vehicle (Ó Domhnaill *et al*., 2023). Hence, equations A1.3 and A1.4 are modified to obtain equations A1.5 and A1.6 (Ó Domhnaill *et al*., 2023):

$$P_1 = IDWVKT = \sum_{b=1}^{B} \frac{1}{d_\mathrm{b}} \sum_{r=1}^{R} EAADT_r, L_r \qquad \text{(A1.5)}$$

and

$$EAADT_r = \sum_{k=1}^{N} E_k N_{k,r} \qquad \text{(A1.6)}$$

where E_k is the emission weighting for vehicle category k, calculated as:

$$E_k = e_k / e_A \qquad \text{(A1.7)}$$

where e_k is the average emission from vehicle type k in a study period and e_A is the average emission from all vehicles in the same study period.

The *Air Pollutant Emission Inventory Guidebook* of the European Monitoring and Evaluation Programme and the European Environment Agency (EEA, 2019) identifies the average emission rate for nitrogen oxides (NO_x) in g/km for each vehicle type and Euro class, including pre-Euro vehicle classes, and an NO_2 fraction (f-NO_2) for each fuel type, which determines the amount of NO_2 emitted based on the quantity of NO_x emitted (Ó Domhnaill *et al*., 2023). This information was used to determine the typical NO_2 emission rate for each type of vehicle, which was then divided by the all-vehicle average emission rate during the time period being studied to determine the NO_2 emission weighting for the vehicle type (Ó Domhnaill *et al*., 2023). The *Irish Bulletin of Vehicle and Driver Statistics* (e.g. Department of Transport, Tourism and Sport, 2019) is published annually and collates data relating to the entire Irish vehicle fleet, such as year of registration, unladen weight, engine capacity and fuel type (Ó Domhnaill *et al*., 2023). These data were employed to determine the Euro classification breakdown of the national vehicle fleet (Ó Domhnaill *et al*., 2023).

The enhanced WS-LUR model for the calculation of ambient NO_2 concentrations was developed in Microsoft Excel. Excel was selected to:

- maximise accessibility to the model, with a view to future use and development;
- minimise the training required to utilise the basic functions of the model – the model has been designed so that all functions or commands are programmed in the background and key spreadsheets automatically update when the user inputs a value;
- facilitate data management – data for this research are obtained from a number of different sources that are typically available in an Excel-compatible format or can be transferred to Excel format after the main elements of the analysis have been completed.

A1.1.3 Data

Data on land use, traffic and meteorological conditions are required to define the values of the predictor variables and wind direction fractions employed in the WS-LUR model. Data defining the conditions at and surrounding fixed air quality monitoring sites are required for the development and calibration of the WS-LUR model (Ó Domhnaill *et al*., 2023). Subsequently, equivalent meteorological data defining conditions at and around any receptor location at which the ambient NO_2 concentration is to be calculated are also required (Ó Domhnaill *et al*., 2023).

Meteorological data were retrieved from the Met Éireann website (Met Éireann, 2019). All monitoring stations, including offshore stations, were included in the analysis, to achieve the most accurate representation of conditions throughout the country and in particular around coastal areas. Data analysis was carried out for each station to determine the average temperature, precipitation and relative humidity, and average wind speed and proportions by wind sector. To calculate the ambient NO_2 concentration at a given receptor, meteorological variables at the receptor location were calculated by interpolation.

Coordination of Information on the Environment (CORINE) land use mapping (Copernicus, 2020) was used to identify the areas of land categorised as agricultural or natural. CORINE mapping has been carried out by the EPA for the EEA on a 6-year basis since 2000, with the latest completed in 2018, and is part of a Europe-wide survey. Land is divided into five main categories (artificial surfaces, agricultural, forest and semi-natural, wetlands and water bodies), which are further divided into 45 subcategories. For application to the WS-LUR model, the 2018 data were reduced to two categories: agricultural/natural and non-agricultural/non-natural. Using ArcGIS and Excel, the area in each category was determined for each principal directional sector at all receptor grid points. A similar procedure was followed to determine the number of commercial properties located within each principal directional sector from data on the locations of commercial properties retrieved from the EPA geographical information system department (personal communication, 2019) and the national postal service/GeoDirectory (GeoDirectory, 2020).

Road type data and traffic flows were obtained from the NTA model for 2016 (NTA, 2020). The data were limited to the east region of Ireland, which includes all of Leinster and Counties Cavan and Monaghan. All route types (motorway, national, rural and local) are covered by the National Transport model, which provided data on traffic flows for various trip categories for all time periods (a.m. peak, school run, lunchtime, off-peak and p.m. peak). The flow values for each trip category within these time periods were provided in terms of passenger car units (PCUs), which, for application to the WS-LUR model, were converted to vehicle numbers for each vehicle type. The enhanced WS-LUR model requires AADT data to be split by vehicle type (i.e. cars, LGVs, HDVs, etc.) to be able to apply emission weightings in the *IDWVKT* variable. The conversion of PCU flows into actual vehicle flows used the PCU factors for each vehicle type and the period to hour (PtH) factors that accompanied the modelled traffic data. The period flow (representing a 1-hour flow within a period) was transferred to total flows for each period by using the PtH factors and then combining them to find the AADT flows.

Calculation of the *IDWVKT* predictor variable values in equation A1.5 requires the emission weighting, E_k, for each vehicle category, for which data on the average emission rate from each vehicle type, e_k, and the average emission rate from all vehicles, e_A, are required. The primary sources employed for these data were the *Air Pollutant Emission Inventory Guidebook*

(EEA, 2019) and the *Irish Bulletin of Vehicle and Driver Statistics* (Department of Transport, Tourism and Sport, 2010–2020).

The breakdowns of the vehicle fleet for each of the pre-set years in the model and the original study period, 2010–2012, were calculated and, from these data, the average NO_2 emitted by a vehicle in each time period was calculated (Ó Domhnaill *et al*., 2023). This average emission value was used to determine the NO_2 emission weighting of every vehicle type/Euro class and alter the *IDWVKT* variable in the WS-LUR model formula (Ó Domhnaill *et al*., 2023). Details of the fuel type, unladen weights, engine capacities and year when first licensed are available in the *Irish Bulletin of Vehicle and Driver Statistics* to determine the Euro class breakdown of each vehicle category (i.e. passenger cars, LGVs, HDVs, etc.), as shown in the flow diagram in Figure A1.2 (Ó Domhnaill *et al*., 2023).

A2.1 Validation and Testing of the Improved WS-LUR Model

A2.1.1 Model validation

To validate the model, the results achieved in the original study by Naughton *et al*. (2018) were compared with those obtained using the new model, which accounts for the vehicle fleet breakdown (Ó Domhnaill *et al*., 2023). This was done by calculating the *IDWVKT* variable so that overall traffic emissions in the study years analysed in this project (2016–2018) match those in the original study years analysed by Naughton *et al*. (2018) (2010–2012) (Ó Domhnaill *et al*., 2023). Tables A1.1–A1.4 identify

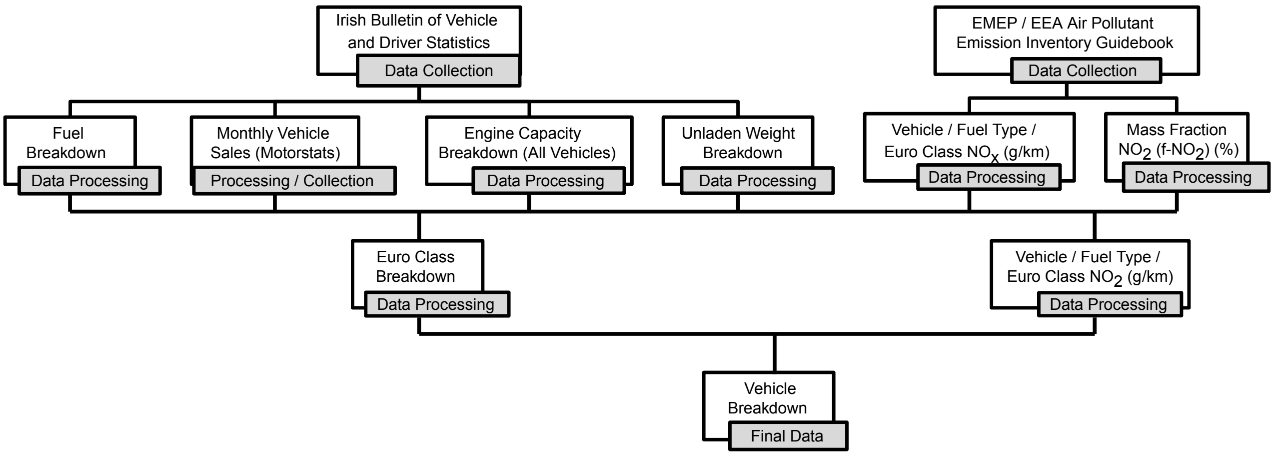

Figure A1.2. Vehicle breakdown analysis. Source: reproduced from Ó Domhnaill *et al*., 2023, Integrated transportation and land use regression modelling for nitrogen dioxide mitigation, *Transportation Research Part D: Transport and Environment* 115: 103572, https://doi.org/10.1016/j.trd.2022.103572.

Table A1.1. Original model period: 2010–2012 model validation

Vehicle type	NO_2 emission weighting	Vehicle type breakdown	NO_2 emission weighting x vehicle type breakdown
Passenger cars	0.712	82.85%	0.590
Light commercial vehicles	2.515	12.81%	0.322
Heavy-duty vehicles	3.498	1.24%	0.043
Large public service vehicles	7.381	0.36%	0.027
Motorcycles	0.076	1.61%	0.001
Small public service vehicles	1.439	1.12%	0.016
Electric vehicles	0	0.01%	0
Resultant weighting			1

Source: Ó Domhnaill *et al*. (2023).

Table A1.2. Original model period: 2016 model validation

Vehicle type	NO_2 emission weighting	Vehicle type breakdown	NO_2 emission weighting x vehicle type breakdown
Passenger cars	0.803	83.05%	0.667
Light commercial vehicles	2.199	12.59%	0.277
Heavy-duty vehicles	1.963	1.44%	0.028
Large public service vehicles	3.900	0.40%	0.016
Motorcycles	0.052	1.56%	0.001
Small public service vehicles	1.265	0.89%	0.011
Electric vehicles	0	0.07%	0
Resultant weighting			1

Source: Ó Domhnaill *et al*. (2023).

Table A1.3. Original model period: 2017 model validation

Vehicle type	NO_2 emission weighting	Vehicle type breakdown	NO_2 emission weighting x vehicle type breakdown
Passenger cars	0.808	82.97%	0.670
Light commercial vehicles	2.219	12.57%	0.279
Heavy-duty vehicles	1.742	1.46%	0.026
Large public service vehicles	3.380	0.42%	0.014
Motorcycles	0.051	1.60%	0.001
Small public service vehicles	1.216	0.86%	0.010
Electric vehicles	0	0.11%	0
Resultant weighting			1

Source: Ó Domhnaill *et al*. (2023).

Table A1.4. Original model period: 2018 model validation

Vehicle type	NO_2 emission weighting	Vehicle type breakdown	NO_2 emission weighting x vehicle type breakdown
Passenger cars	0.821	82.94%	0.681
Light commercial vehicles	2.170	12.53%	0.272
Heavy-duty vehicles	1.568	1.48%	0.023
Large public service vehicles	2.966	0.43%	0.013
Motorcycles	0.051	1.58%	0.001
Small public service vehicles	1.191	0.84%	0.010
Electric vehicles	0	0.19%	0
Resultant weighting			1

Source: Ó Domhnaill *et al*. (2023).

the NO_2 emission weighting and vehicle type breakdown for each vehicle type in each study year. The resultant weighting factor represents the overall weighting applied to the *IDWVKT* variable. As this value is equal to 1 in each case, the overall weighting of the *IDWVKT* variable is equal in the original and new study years (Ó Domhnaill *et al*., 2023). This supports the direct comparison of the concentration results obtained with the original and new models while introducing sufficient detail to identify particular vehicle types that contribute to elevated concentrations at a given location (Ó Domhnaill *et al*., 2023).

A2.1.2 Monitored and modelled concentration comparisons

The annual average NO_2 concentrations measured at EPA monitoring stations were compared with the concentrations calculated using the original model methodology and the new model methodology (Ó Domhnaill *et al*., 2023). For the purposes of the comparisons below, two new model options were compared with the original model, as defined below (Ó Domhnaill *et al*., 2023):

- **Original model – AADT only:** this option calculates the IDWVKT values as per the original model methodology by Naughton *et al*. (2018) in which only the AADT value is considered and all vehicle types are weighted equally (Ó Domhnaill *et al*., 2023).
- **New model A – original vehicle type composition:** this option calculates the IDWVKT values using the vehicle type breakdown and NO_2 emission weightings for the 2010–2012 study period (Ó Domhnaill *et al*., 2023).
- **New model B – vehicle type and Euro classification:** this option calculates the IDWVKT values using the vehicle type breakdown and NO_2 emission weightings for one of the 2016–2018 pre-set years (Ó Domhnaill *et al*., 2023).

Table A1.5 summarises the measured concentrations and various modelling concentrations at each of the sites, and these data are compared graphically in Figures A1.3–A1.5. The difference between the measured and modelled concentrations varies more between sites than between model versions (Ó Domhnaill *et al*., 2023). At most locations the two values are relatively close, but at some locations (Ballyfermot, Winetavern Street and St John’s Road) the differences are large (Ó Domhnaill *et al*., 2023). LUR models assume that the relationship between concentrations and nearby sources is the same throughout the modelled domain, which in this case is the whole country (Ó Domhnaill *et al*., 2023). Where large differences between measured and modelled concentrations are observed, this implies that some other effects that are not well captured by the model are locally important (Ó Domhnaill *et al*., 2023). Figures A1.3–A1.5 display standard error bars, which show the range of concentrations that could be expected above and below the model estimate given the quality of the input data used to calibrate the model. It is clear that the measured values at most sites fall within or very close to this standard error range, indicating that the model performed well at those locations. The model is able to distinguish between locations that experience high or low NO_2 concentrations, implying that it is a suitable tool for evaluating the ability of potential mitigation strategies to improve air quality at specific locations (Ó Domhnaill *et al*., 2023).

The concentrations for the original model methodology and the new model B methodology were consistently similar throughout (Ó Domhnaill *et al*., 2023). This reflects the fact that the differences between the models affect only one of the predictor variables (*IDWVKT*) and the emissions weightings have been calibrated to maintain overall consistency with the original model (Ó Domhnaill *et al*., 2023). This similarity in results validates the ability of the new model method to retain the accuracy of the original model while introducing the potential to analyse the traffic variables in more detail (Ó Domhnaill *et al*., 2023).

The similarity in results obtained with the original and new model methodologies in rural environments, such as Seville Lodge, Emo Court and Kilkitt, highlights that the composition of the vehicle fleet in these locations is close to the national average (Ó Domhnaill *et al*., 2023). In contrast, at a number of urban locations, such as Coleraine Street, St John’s Road and Winetavern Street, higher concentration estimates are given by the new models, reflecting the much higher percentage of vehicles (LPSVs and HDVs) with above-average NO_2 emission rates (Ó Domhnaill *et al*., 2023). This indicates that the new model can be utilised to develop mitigation measures that target particular vehicle types, such as Euro class restrictions on routes or migrating parts of the vehicle fleet to low-emission vehicles (Ó Domhnaill *et al*., 2023).

The limitation in available traffic data, which were available only for the eastern region of Ireland (Leinster and parts of Ulster), affected the scope of the model validation. Nevertheless, a complete set of 38 measurements obtained over a 3-year period at 16 different sites in this region (see Table A1.5) were included in the comparative analysis (Ó Domhnaill *et al*., 2023). Measured concentrations were within the standard error range of the model for 50% of observations (19 measurements) using the original

Table A1.5. Measured and modelled NO_2 concentrations at EPA monitoring locations

Year/monitoring station	Measured concentration (μg/m³)	Original model concentration (μg/m³)	New model A concentration (μg/m³)	New model B concentration (μg/m³)
2018 Seville Lodge, Kilkenny	5.90	4.987±3.421	4.990±3.421	4.987±3.421
2017 Seville Lodge, Kilkenny	5.37	4.879±3.436	4.880±3.436	4.879±3.436
2016 Seville Lodge, Kilkenny	6.44	5.282±3.371	5.285±3.371	5.283±3.371
2018 Emo Court, Laois	5.53	9.159±3.045	9.311±3.058	9.165±3.045
2017 Emo Court, Laois	4.16	9.291±3.024	9.439±3.037	9.308±3.026
2016 Emo Court, Laois	5.00	9.467±2.975	9.602±2.987	9.498±2.978
2018 Portlaoise, Laois	11.21	17.122±3.929	17.379±3.952	17.102±3.928
2017 Portlaoise, Laois	11.07	16.435±3.697	16.652±3.716	16.427±3.696
2016 Portlaoise, Laois	12.45	18.155±4.139	18.446±4.164	18.218±4.144
2018 Dundalk, Louth	13.64	19.787±5.012	19.967±5.027	19.784±5.012
2018 Kilkitt, Monaghan	3.43	4.850±3.395	4.833±3.393	4.837±3.394
2017 Kilkitt, Monaghan	2.94	4.943±3.379	4.925±3.377	4.928±3.377
2016 Kilkitt, Monaghan	3.70	5.129±3.345	5.112±3.343	5.115±3.344
2016 Enniscorthy, Wexford	11.15	12.566±4.242	12.572±4.242	12.570±4.242
2018 Ballyfermot, Dublin	17.52	31.875±7.043	34.111±7.237	32.493±7.097
2017 Ballyfermot, Dublin	16.58	33.736±7.565	36.227±7.781	34.568±7.637
2016 Ballyfermot, Dublin	17.50	32.685±7.165	34.993±7.365	33.656±7.250
2018 Blanchardstown, Dublin	31.75	39.034±9.290	40.369±9.406	39.076±9.294
2017 Blanchardstown, Dublin	26.79	37.955±9.364	39.007±9.456	38.025±9.370
2016 Blanchardstown, Dublin	33.09	38.917±9.292	40.205±9.404	39.223±9.319
2017 Coleraine Street, Dublin	26.65	38.056±9.757	40.484±9.968	39.035±9.842
2016 Coleraine Street, Dublin	28.32	39.653±10.043	42.239±10.268	40.878±10.150
2018 Davitt Road, Dublin	25.72	32.689±7.304	34.910±7.497	33.311±7.358
2018 Dún Laoghaire, Dublin	19.09	22.347±5.903	22.661±5.930	22.375±5.905
2017 Dún Laoghaire, Dublin	17.92	21.966±5.769	22.356±5.803	22.039±5.775
2016 Dún Laoghaire, Dublin	18.67	22.704±5.964	23.046±5.994	22.808±5.973
2018 Rathmines, Dublin	21.12	27.073±6.808	28.328±6.918	27.469±6.843
2017 Rathmines, Dublin	17.09	26.342±6.825	27.566±6.931	26.824±6.866
2016 Rathmines, Dublin	20.01	27.200±6.820	28.480±6.931	27.789±6.871
2018 Ringsend, Dublin	27.22	20.950±4.891	22.448±5.021	21.370±4.927
2017 Ringsend, Dublin	22.26	21.501±4.990	23.314±5.147	22.143±5.045
2018 St John's Road, Dublin	44.50	29.743±6.630	32.583±6.876	30.657±6.709
2018 Swords, Dublin	16.45	21.975±5.737	22.436±5.777	21.963±5.736
2017 Swords, Dublin	14.11	19.059±5.273	19.462±5.308	19.088±5.276
2016 Swords, Dublin	15.86	20.426±5.496	20.828±5.531	20.507±5.503
2018 Winetavern Street, Dublin	29.00	43.681±11.181	46.542±11.429	44.612±11.262
2017 Winetavern Street, Dublin	27.19	43.304±11.299	45.891±11.523	44.305±11.386
2016 Winetavern Street, Dublin	36.71	43.679±11.183	46.523±11.429	44.998±11.297

Locations and measured concentrations: EPA (2019a).

model methodology; 42.1% (16 measurements) using the new model A methodology; and 47.4% (18 measurements) using the new model B methodology, as shown in Figures A1.3–A1.5 (Ó Domhnaill *et al.*, 2023). In the original study, 68% of the measured concentrations were within the standard error range of the modelled concentrations (Ó Domhnaill *et al.*, 2023). However, even as the sample size has remained similar to the original study (16 locations compared with 15 locations),

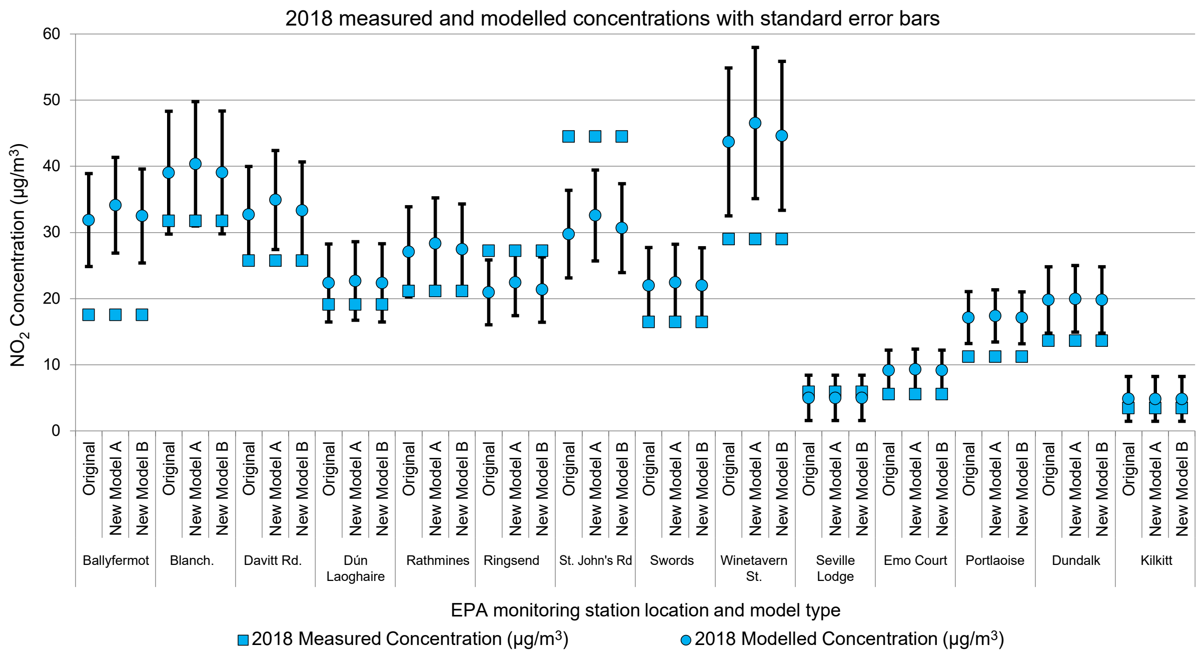

Figure A1.3. 2018 measured and modelled NO_2 concentrations with standard error high–low bars.

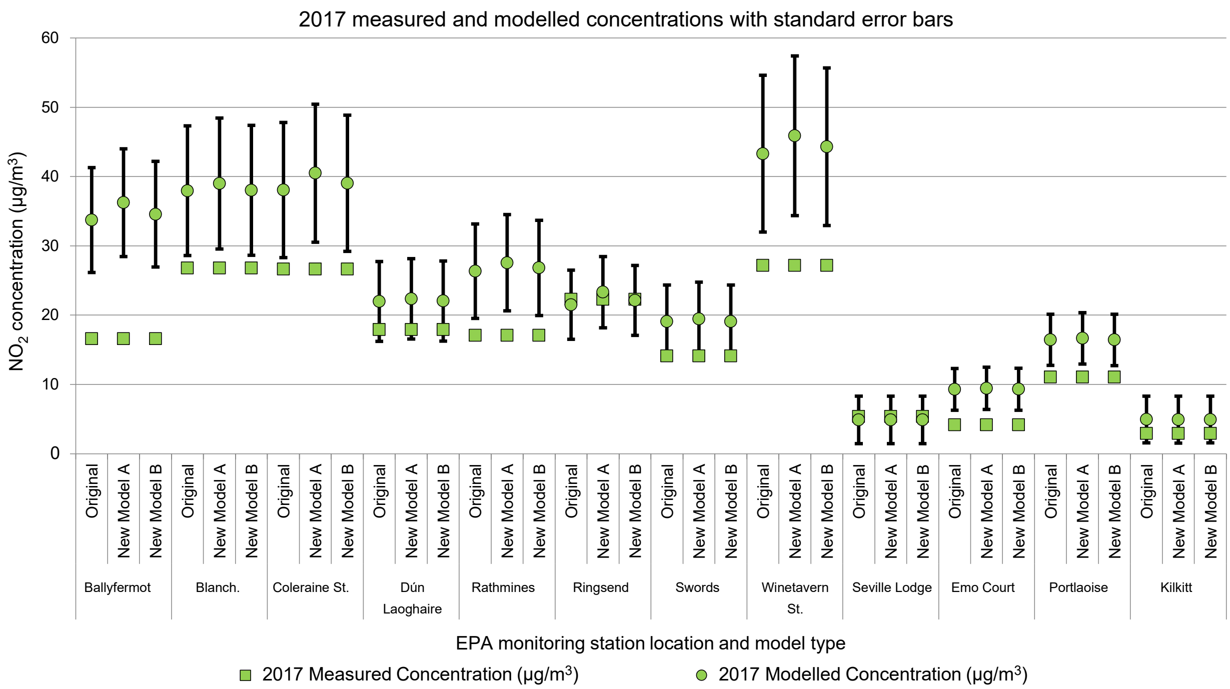

Figure A1.4. 2017 measured and modelled NO_2 concentrations with standard error high–low bars.

the locations have changed considerably, with only nine of the original 15 locations included in the 2016 to 2018 comparison (Ó Domhnaill *et al.*, 2023). Moreover, six of these stations are located relatively close to each other in Dublin City, which limits analysis of spatial (environmental and meteorological) and temporal (traffic) variability in the study (Ó Domhnaill *et al.*, 2023).

In any distribution of data, approximately 95% of the measurements should be within the double standard error ranges, and approximately 95% (94.74%) of measurements in the original model and new model B methodologies were within the double standard error ranges (Ó Domhnaill *et al.*, 2023). The new model A methodology captured 97.37% of

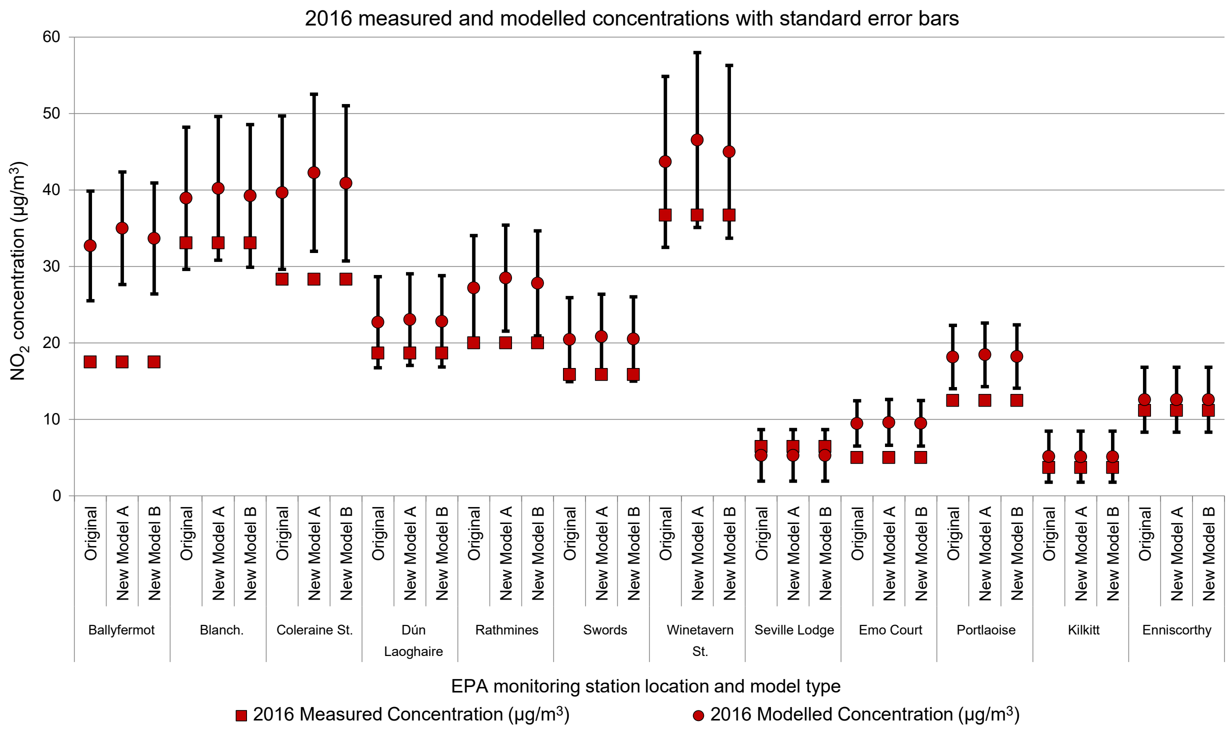

Figure A1.5. 2016 measured and modelled NO_2 concentrations with standard error high–low bars.

measurements when considering the double standard error ranges (Ó Domhnaill *et al.*, 2023).

All model methodologies overestimated the NO_2 concentrations, with two exceptions where the NO_2 concentrations were underestimated, both in 2018, at St John's Road and Ringsend (Ó Domhnaill *et al.*, 2023). This was the first year the St John's Road monitoring site was active; further sampling at this site could confirm whether there are other factors, not captured by the model, that contribute to NO_2 concentrations (Ó Domhnaill *et al.*, 2023). It should be noted that in 2019 the annual EU limit value for NO_2 at St John's Road was exceeded (Ó Domhnaill *et al.*, 2023). The exceedance necessitated the preparation of the Dublin Region Air Quality Plan (Dublin City Council *et al.*, 2021; Ó Domhnaill *et al.*, 2023). The plan sets out 14 measures and a number of associated actions to address the exceedance of the NO_2 annual limit value (Ó Domhnaill *et al.*, 2023).

The Ringsend monitoring site was active only in 2017 and 2018 during the study period (Ó Domhnaill *et al.*, 2023). In 2017 the measured values agreed well with the modelled concentrations, whereas in 2018 they were marginally outside the standard error range (Ó Domhnaill *et al.*, 2023). The meteorological conditions were very different in 2017 and 2018, with approximately 59% of the wind coming from a west/south-westerly direction and 16% from an east/south-easterly direction in 2017, compared with 45% west/south-westerly and 23.5% east/south-easterly proportions in 2018 (Ó Domhnaill *et al.*, 2023). This higher proportion of easterly winds in 2018 may have influenced the higher average concentration measured that year (Ó Domhnaill *et al.*, 2023).

The original model captured 78% of the spatial variability in NO_2 with a cross-validation R^2 of 77.4% (Naughton *et al.*, 2018). The cross-validation R^2 was slightly lower when analysing the 2016 to 2018 measurements against the original model methodology, at 75.44%, whereas the new model A and new model B methodologies were slightly better at 76.08% and 75.58%, respectively, as shown in Figures A1.6–A1.8.

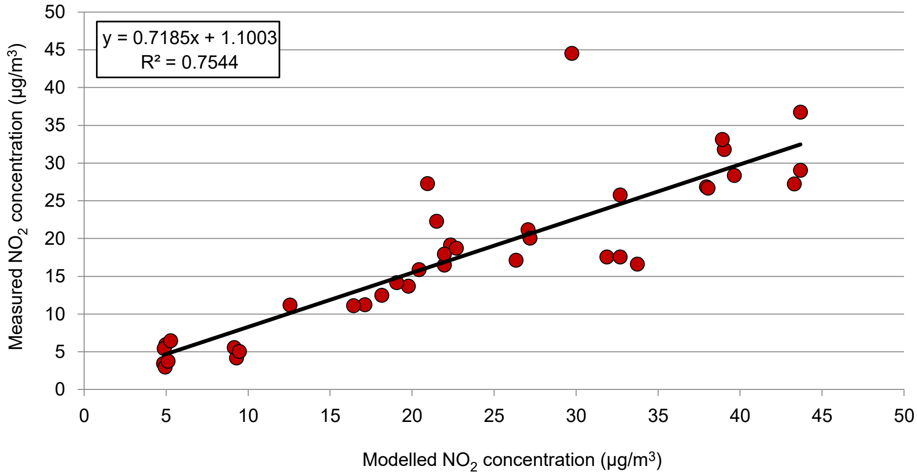

Figure A1.6. Measured versus modelled NO_2 concentrations (2016–2018) – original model methodology.

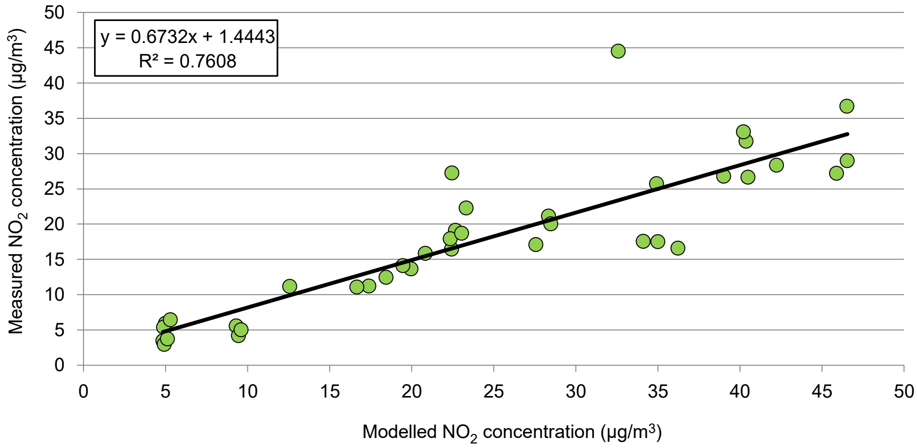

Figure A1.7. Measured versus modelled NO_2 concentrations (2016–2018) – new model A methodology.

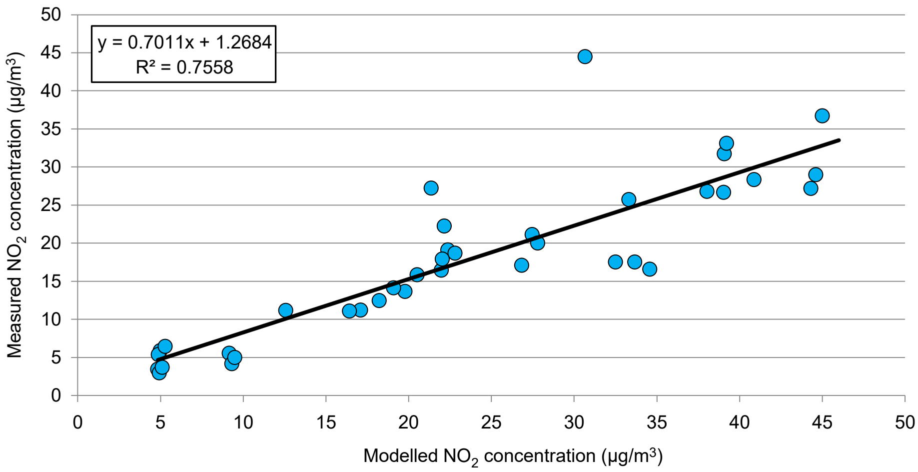

Figure A1.8. Measured versus modelled NO_2 concentrations (2016–2018) – new model B methodology.

Appendix 2 Publications Arising from this Research

Carthy, P., Ó Domhnaill, A., O'Mahony, M., Nolan, A., Moriarty, F., Broderick, B., Hennessy, M., Donnelly, A., Naughton, O. and Lyons, S., 2020. Local NO_2 concentrations and asthma among over-50s in Ireland: a microdata analysis. *International Journal of Epidemiology* 49(6): 1899–1908.

O'Mahony, M., Broderick, B., Hennessy, M. and Gallagher, J., 2019. Awareness of health impacts of NO_2 and, potential responses to diesel vehicle bans and proposals to cease their production. *Annual Meeting of the Transportation Research Board*, Washington, DC, January 2019, p. 12.

Ó Domhnaill, A., Broderick, B. and O'Mahony, M., 2023. Integrated transportation and land use regression modelling for nitrogen dioxide mitigation. *Transportation Research Part D: Transport and Environment* 115: 103572.

An Ghníomhaireacht Um Chaomhnú Comhshaoil

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

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

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

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

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

I measc ár gcuid freagrachtaí tá:

Ceadúnú

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

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil

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

Bainistíocht Dramhaíola agus Ceimiceáin sa Chomhshaol

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

Bainistíocht Uisce

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

Eolaíocht Aeráide & Athrú Aeráide

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

Monatóireacht & Measúnú ar an gComhshaol

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

Taighde agus Forbairt Comhshaoil

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

Cosaint Raideolaíoch

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

Treoir, Ardú Feasachta agus Faisnéis Inrochtana

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

Comhpháirtíocht agus Líonrú

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

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil

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

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

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

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