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Investigation of Effects of Covid-19 Restrictions on Air Quality in Northern Ireland

Report for DAERA

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Executive summary

This report describes an investigation carried out by Ricardo on behalf of Northern Ireland's Department of Agriculture, Environment and Rural Affairs. The aim of the study was to investigate the effects of the first Covid-19 'lockdown' restrictions in the spring and early summer of 2020, on air quality in Northern Ireland.

The report focuses on the period 1st January to 31st May 2020. This spans the early weeks of the pandemic, the onset of social distancing measures on 16th March, the beginning of the 'lockdown' period on 23rd March, through to the end of May 2020 when some easing of restrictions had begun. (Data from previous years, and in some cases later months, have been used for comparison).

Information on power generation, industrial activity, agriculture, air and rail traffic, industrial and domestic waste burning, wildfires and traffic count data were provided by various organisations via DAERA. Information on emission sources was taken from the National Atmospheric Emission Inventory (NAEI). Together these were used to qualitatively and semi-quantitatively assess the likely effects of the lockdown restrictions on pollutant emissions.

Emissions from industrial processes are likely to have decreased, though it was not possible to quantify this. Electricity demand statistics for the lockdown period indicated that any reduction in emissions from the power generation sector was likely to be small: probably less than 1% of the Northern Ireland total in the cases of both sulphur dioxide (SO_2) and oxides of nitrogen (NO_X). There was evidence of an increase in domestic waste burning complaints in some, though not all, districts.

Traffic count data from 14 locations showed that lockdown caused dramatic decreases in road traffic: vehicle numbers (particularly cars) began to fall sharply when social distancing began (16th March), typically dropping to around one third of usual levels in early April. With road vehicles usually accounting for 30% of Northern Ireland's total NO_X emissions, the lockdown restrictions are estimated to have resulted in a short-term reduction of 20% in the region's emitted NO_X during the first few weeks of lockdown. At most locations, traffic counts then gradually began to recover steadily through the rest of April, May and June. However, there is some evidence of a longer-term reduction in traffic count: at most of the 14 traffic count locations, traffic counts had still not returned to pre-lockdown levels by the start of July.

Non-road transport – flights and rail services – also showed dramatic decreases during the lockdown period.

Air quality data came from Northern Ireland's network of automatic monitoring sites, available on the Northern Ireland Air Quality Website at https://www.airqualityni.co.uk/. Data were analysed using a range of statistical models developed by Ricardo. These models were used to develop a 'counterfactual' (i.e. business as usual, or BAU) scenario for the expected pollutant concentrations if Covid-19 had not occurred.

Measured ambient NO_X and NO_2 concentrations fell substantially during lockdown: on average, over the period from the beginning of lockdown to the end of June, NO_2 concentrations were 44% lower than BAU. This corresponds to an absolute average reduction of 13 µg m^{-3}. The four monitoring sites which had exceeded the Air Quality Strategy objective of 40 µg m^{-3} for annual mean NO_2 in recent years (Belfast Stockman's Lane, Downpatrick Roadside, Limavady Dungiven and Newry Canal Street) all had mean concentrations below 30 µg m^{-3} during the lockdown period.

By contrast, ambient ozone concentrations at the two urban sites in Northern Ireland which monitor this pollutant (Belfast Centre and Derry Rosemount) showed notable increases compared to BAU, of 23% and 20% respectively, while the rural site at Lough Navar showed a much smaller increase of just 3%. Ozone is a seasonal pollutant, formed in the presence of sunlight, and an increase through the spring months would normally be expected. However, the fact that the urban sites exhibited a greater increase compared to BAU than the rural site suggests that urban O_3 was also influenced by the lower than normal levels of NO (which would usually react with O_3 and remove it from the air). (Despite this, it would be a mistake to conclude that NO_X emissions are beneficial: NO_X is implicated

in the formation of ozone as well as contributing to its removal, has its own impacts on air quality, and is often produced along with other harmful pollutants.)

The analysis of PM_{10} concentrations was more challenging, as particulate pollution tends to be dominated by regional background levels rather than local primary emissions. Also, there have been changes to the monitoring methods at some sites over the past two years. This study focussed on changes to the 'urban increment' above the rural background concentration. The pattern was less clear for PM_{10} than for other pollutants, with some sites showing an increase and others showing a decrease. On average there was a small increase in PM_{10} compared to BAU (approximately 1 µg m^{-3}). Changes in PM_{10} should be considered as uncertain, compared with the changes seen for other pollutants.

It was not possible to carry out the same type of analysis for $PM_{2.5}$: the calculation of the 'urban increment' requires regional background data from a rural monitoring site in Northern Ireland (Lough Navar being currently the only one). This site has measured PM_{10} for many years but only began measuring $PM_{2.5}$ in July 2018. This made it difficult to model the BAU scenario robustly, for $PM_{2.5}$.

Two of the four sites that monitored black carbon showed some evidence of a decrease during the lockdown period. Black carbon in air is directly linked to emissions from combustion processes in transport, domestic heating or industry, and from waste burning or wildfires.

There was no clear pattern of concentration change in the case of SO_2, with some monitoring sites showing an increase and some showing a decrease. However, concentrations of this pollutant are very low, creating some challenges for measurement.

There were several significant periods of elevated pollution during the period of investigation, in which concentrations of PM_{10} or ozone went into the 'Moderate' band as defined by the Daily Air Quality Index. In particular, during April and May there were three seasonal ozone pollution episodes. These were associated with warm, sunny, still weather with relatively little wind: they were not confined to Northern Ireland but affected large parts of England and Wales. Although the ozone episodes were not caused by the lockdown, it is possible that the lockdown exacerbated ozone levels in urban areas, by reducing the amount of ambient NO available to 'scavenge' O_3 from the air. This effect may have been sufficient to cause ozone concentrations in urban areas to go into the 'Moderate' band, when they might otherwise have remained 'Low'.

In summary:

- The Covid-19 lockdown restrictions in Northern Ireland resulted in a dramatic and substantial decrease in road traffic. Although traffic counts then began to increase steadily, they had not returned to pre-lockdown levels even by the beginning of July.
- This led to a substantial measured reduction in ambient NO_X and NO_2 concentrations.
- However, air quality over the months of April and May was largely dominated by seasonal and regional meteorology, with some significant periods of elevated ozone concentrations.
- The lowered NO_X emissions may even have exacerbated the ozone episodes in urban areas, due to reduced 'scavenging' of O_3 by NO (although this should not be interpreted as meaning increased NO_X emissions are to be encouraged).
- The impact of lockdown restrictions on PM_{10} particulate pollution was less clear, with considerable variation between monitoring sites.
- The impacts on SO_2 concentrations also appeared to be more variable between locations, with no clear pattern.
- Therefore, without detracting from the fact that there was a clear reduction for one group of pollutants – NO_X – it would be an over-simplification to state that overall air quality in Northern Ireland improved during lockdown.

Northern Ireland's first Air Quality App was launched in May 2020. The App gives the public up to date information on average air pollution levels across Northern Ireland and a five-day air quality forecast. Users can set up a push notification to alert them to when levels of elevated pollutants are detected or forecast. (Further information can be found at https://www.airqualityni.co.uk/stay-informed).

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1 Introduction

This report describes an investigation of the effects of the Covid-19 'lockdown' restrictions on air quality in Northern Ireland, during the first five months of 2020 (1st January to 31st May 2020).

This report has been prepared on behalf of Northern Ireland's Department of Agriculture, Environment and Rural Affairs (DAERA), by Ricardo.

1.1 Background

February and March 2020 saw the beginning of the Covid-19 coronavirus pandemic in the UK. In response to the threat, the UK Government and Devolved Administrations imposed a series of restrictions, starting with social distancing advice on 16th March, followed by the so-called 'lockdown' from 23rd March. Under lockdown, people were told to work from home where possible, go out only for essential purposes such as work which could not be done from home, and buying food or medicines. They were advised to avoid public transport, and to travel only if absolutely necessary. Schools, non-essential shops, restaurants, pubs and leisure facilities were closed. The lockdown restrictions remained in place throughout April and May 2020, with some being gradually eased in subsequent months. At the time of writing (early 2021) many restrictions are still in place and some – such as social distancing and the wearing of face coverings in indoor public spaces – are expected to remain for some months.

1.2 Scope of This Report

The Covid-19 lockdown imposed substantial restrictions on public activity, travel, commerce and industry. These changes may have had impacts on the emission of various air pollutants. This report aims to investigate the effects of the lockdown on air quality in Northern Ireland. The scope of the report is as follows.

The investigation first aims to provide a qualitive or semi-quantitative review of changes in air pollutant emissions across Northern Ireland, based on data provided by DAERA, other Northern Ireland departments, local government and private entities, for the following sectors:

- Transport: road transport (traffic count data), air, rail and shipping data (if available)
- Power generation and demand
- Industrial activity
- Agriculture
- Complaints to District Councils of nuisance bonfires and domestic burning
- Information on dates and locations of large wildfires.

The investigation then attempts to analyse and quantify the effect the lockdown has had on ambient air pollutant concentrations in Northern Ireland, based on measurements from Northern Ireland's network of automatic air quality monitoring stations.

The pollutants covered are as follows:

- Oxides of nitrogen: nitric oxide (NO), nitrogen dioxide (NO_2) and total nitrogen oxides (NO_X).
- Ozone (O_3)
- Particulate matter as PM_{10} and $PM_{2.5}$
- Black carbon
- Sulphur dioxide (SO_2)
- Carbon monoxide (CO).

The main period covered by this report is 1st January to 31st May 2020. The main focus is on the period from 16th March, when the UK Government issued social distancing advice, through the beginning of 'lockdown' on 23rd March, to 31st May 2020 after which the lockdown restrictions gradually began to be eased. In some cases, data from previous years, or later months, are used for comparison or to provide context.

1.3 Overview of Pollutants

As background information, the main sources and health impacts of the pollutants featured in this report are briefly described below. This information is summarised from the information on the '*Pollutants*' page of the Northern Ireland Air Quality website, see https://www.airqualityni.co.uk/air-quality/pollutants.

1.3.1 Oxides of Nitrogen

These are gases formed when nitrogen combines with oxygen. This can happen when any fuel is burned at high temperature in the presence of air: NO_X is formed by most combustion processes, such as vehicle engines, domestic heating, power generation and industrial processes. These emit a mixture of oxides of nitrogen, primarily nitric oxide (NO) and nitrogen dioxide (NO_2), together referred to as NO_X.

NO_2 is a respiratory irritant: it can irritate the airways and lungs. NO is not considered to be harmful to health. However, once released to the atmosphere, an NO molecule will rapidly join up with another oxygen atom, making nitrogen dioxide (NO_2).

Also, NOx is involved in the formation of another important air pollutant: ozone (O_3). In the presence of sunlight, and especially during warm weather, oxides of nitrogen react with some reactive Volatile Organic Compounds (VOCs), to produce ozone. NOx emissions also contribute to damage of ecosystems such as land, lakes and rivers.

The Air Quality Strategy (Department for Environment Food and Rural Affairs, 2007) sets objectives for NO_2, which are met throughout most of Northern Ireland. However, there are several monitoring sites near busy roads which have measured exceedances of the Air Quality Strategy (AQS) objectives in recent years, so NO_2 is a pollutant of concern in Northern Ireland.

1.3.2 Ozone

Ozone (O_3) is found naturally in our atmosphere. High up in the atmosphere, ozone is essential. A layer of air containing high concentrations of ozone (the ozone layer) protects life on earth from the sun's harmful ultraviolet rays. At ground level however, it is an air pollutant.

Ozone is not emitted directly from any man-made source in any significant quantities. In the lower atmosphere, O_3 is mostly formed by chemical reactions between other groups of so-called 'precursor' pollutants – VOCs and NO_X. These reactions are initiated by sunlight and accelerated by high temperatures (as described in a graphic published by the USEPA, here: https://www.epa.gov/ground-level-ozone-pollution/ground-level-ozone-basics). As a result, ground-level O_3 pollution is usually worse in the summer, especially during warm, sunny weather.

The chemical reactions which produce ozone can take hours or days. As a result, ozone measured at a particular location may have arisen from VOC and NOx emissions many hundreds or even thousands of miles away. Ozone is therefore considered a 'transboundary' pollutant, and maximum concentrations generally occur some distance downwind of the original sources of precursor emissions – often in rural areas.

Above, it is explained that oxides of nitrogen are involved in the formation of O_3. They are also involved in one of the processes by which it is removed from the air: reaction of nitric oxide (NO) with O_3. This so-called 'scavenging' process can actually lower O_3 concentrations in urban areas - another reason why O_3 concentrations are often highest in rural areas. (However, this does not mean that NO_X emissions should be encouraged).

Because of its dependence on weather conditions, ozone in Northern Ireland has in the past exceeded Air Quality Strategy objectives in some years but not in others.

Ozone has a wide range of health and ecosystem impacts. It irritates the eyes and respiratory system and can exacerbate the symptoms of asthma and lung problems. Even healthy people may notice symptoms such as irritated eyes or a tickly throat during exercise outdoors when O_3 levels are high. In addition to its serious impacts on human health, ozone is also harmful to many plants, including trees and crops.

1.3.3 Particulate Matter as PM_{10} and $PM_{2.5}$

Particulate matter (PM) consists of a mixture of various materials, small enough to be suspended in the air. These airborne particles are measured in size fractions according to their effective size (referred to as their "median aerodynamic diameter"). Most air quality monitoring measures PM_{10} (that is, particles with a median aerodynamic diameter of 10 micrometres or less) or $PM_{2.5}$ (particles with a median aerodynamic diameter of 2.5 micrometres or less). A micrometre, or micron, is one-thousandth of a millimetre.

Particulate pollution comprises a wide range of materials, both natural and human-made, including:

- soot from combustion sources (such as road vehicle exhaust, domestic solid fuel and oil burning, and industrial combustion);
- Non-exhaust emissions from road traffic (e.g. dust from tyre and break wear, and suspended road dust). As European legislation has reduced vehicle exhaust emissions over recent years, non-exhaust emissions have become a more important source.
- Secondary particulate matter; particles that are not emitted from any source but formed by chemical reactions between other air pollutants, such as oxides of nitrogen, oxides of sulphur and ammonia. The reactions can form particles of chemical compounds such as sulphates and nitrates. Secondary particulate matter can often be transported over very large distances on a national or continental scale.
- Coarse particles and material from construction work, demolition, road work;
- Suspended soils and dusts (e.g. from the Sahara Desert), sea salt, volcanic emissions and biological particles (such as pollen).

Fine particles in the PM_{10} fraction are small enough to be inhaled into the airways of the human respiratory system. There, they can cause inflammation, and exacerbation of heart and lung diseases. The smaller $PM_{2.5}$ particles are considered even more harmful, as they can be carried deep into the lungs. These ultrafine particles may carry surface-absorbed toxic, or carcinogenic, compounds into the body.

Air Quality Strategy objectives for PM_{10} and $PM_{2.5}$ are currently met throughout Northern Ireland.

1.3.4 Black Carbon

Black carbon is dark, carbon-containing particulate matter, emitted mainly from combustion sources: it is one constituent of PM_{10} and $PM_{2.5}$. From the health perspective, it is one of the most important constituents of PM, as black carbon particles may carry harmful surface-absorbed compounds into the body.

Black carbon is measured separately from PM_{10} and $PM_{2.5}$, using an optical technique. It is monitored at four sites in Northern Ireland. It is of particular interest in this study, as levels may reflect changes in PM emissions from local sources, such as residential fuel use, and road traffic.

1.3.5 Sulphur Dioxide

Sulphur dioxide (SO_2) is a gaseous pollutant, formed when a fuel or other material containing sulphur is burned. In the UK, the most important source is the energy industry, followed by residential, institutional and commercial fuel use. The fuels which produce most SO_2 are coal and heavy fuel oils.

Areas with widespread domestic use of coal or oil for heating can have higher local concentrations of SO_2. Historically, this was the case in parts of Northern Ireland: however, SO_2 concentrations have greatly reduced over recent decades, as the availability of natural gas has increased in the region, reducing the use of coal and oil. No exceedances of applicable limit values or objectives for SO_2 have been measured in Northern Ireland since 2001.

SO_2 is one of the chemical compounds that gives coal smoke its distinctive, eye-watering smell. It is a respiratory irritant that can cause the airways to constrict: people with asthma are likely to be particularly sensitive to it. SO_2 is considered more harmful when concentrations of particles and other pollutants are also high. SO_2 is also damaging to the environment; it contributes to acid rain, and can also react with other pollutants to form fine particulate matter.

1.3.6 Carbon Monoxide

Carbon monoxide (CO) is a poisonous gas, formed when a fuel containing carbon is burned, without sufficient oxygen to complete the combustion process and turn it into carbon dioxide (CO_2). This can happen in many combustion systems, including petrol vehicle engines, industrial processes and domestic heating systems. Residential fuel use is now the most significant emission source.

CO is harmful as it prevents the normal transport of oxygen by the blood. It is well known that risk of CO poisoning mainly occurs indoors, due to a faulty boiler or heating appliance. Levels of CO in outdoor air are usually too low to be dangerous. However, in high enough concentrations, CO can lead to a significant reduction in the supply of oxygen to the heart, particularly in people suffering from heart disease. CO is measured at just one site in Northern Ireland: ambient concentrations have been within applicable limit values and objectives for many years.

CO has been included in this study despite low ambient levels, because it might be expected that ambient concentrations of this pollutant would show a measurable change as a result of the lockdown restrictions.

2 Methodology and Approach

2.1 Emissions Data

The estimated pollutant emission data used in this report are taken from the National Atmospheric Emission Inventory (NAEI). The NAEI website is available at https://naei.beis.gov.uk/ . The emissions estimates specifically relating to Northern Ireland (as opposed to the UK) are taken from the Air Pollutant Inventory Report for England, Scotland, Wales and Northern Ireland (Ricardo Energy & Environment, 2019), which is based on data from the NAEI (BEIS, 2020).

2.2 Air Quality Monitoring Data

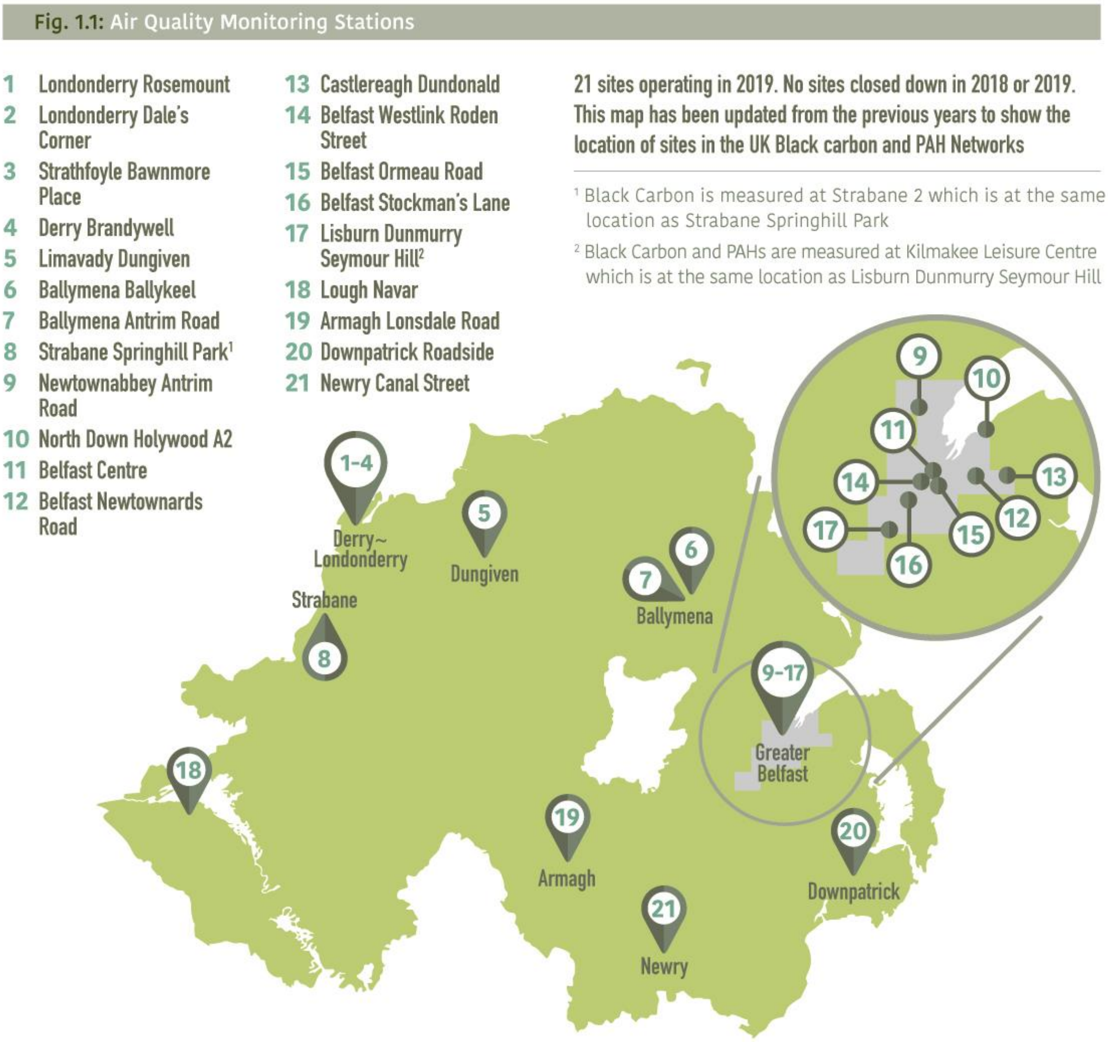
The air quality monitoring data used here are taken from Northern Ireland's network of 20 automatic monitoring stations (also referred to as monitoring sites). Details of the monitoring stations are given in Table 2-1. Data from these sites is available from the Northern Ireland Air Quality Website at https://www.airqualityni.co.uk/ (DAERA, 2020).

Table 2-1 Automatic Air Quality Monitoring Sites in Northern Ireland

Site name	Lat/lon coordinates	Site classification	Pollutants measured during 2020
Armagh Lonsdale Road (referred to as 'Armagh Roadside' in the AURN)	54.353728, -6.654558	Roadside	NO_X, PM_{10}
Ballymena Antrim Road	54.851491, -6.274961	Roadside	NO_X
Ballymena Ballykeel	54.861595, -6.250873	Urban Background	NO_X, PM_{10}, SO_2, black carbon
Belfast Centre	54.599650, -5.928833	Urban Centre	NO_X, PM_{10}, $PM_{2.5}$, SO_2, O_3, CO, black carbon
Belfast Newtownards Road	54.595175, -5.867022	Roadside	NO_X
Belfast Ormeau Road	54.587516, -5.923780	Roadside	NO_X
Belfast Stockman's Lane	54.572586, -5.974944	Roadside	NO_X, PM_{10}
Belfast Westlink Roden Street	54.591753, -5.949517	Roadside	NO_X
Castlereagh Dundonald	54.594577, -5.803313	Roadside	NO_X
Derry Dale's Corner	54.996420, -7.310163	Roadside	NO_X
Derry Rosemount	55.002851, -7.331128	Urban Background	NO_X, PM_{10}, $PM_{2.5}$, SO_2, O_3
Downpatrick Roadside	54.328443, -5.715743	Roadside	NO_X
Limavady Dungiven	54.928407, -6.926810	Roadside	NO_X
Lisburn Dunmurry Seymour Hill *(referred to as 'Kilmakee Leisure Centre' in the black carbon network)*	54.543516, -6.008608	Urban Background	PM_{10}, SO_2, black carbon
Lough Navar	54.439510, -7.900328	Remote	PM_{10}, $PM_{2.5}$, O_3
Newry Canal Street	54.180381, -6.339240	Roadside	NO_X, PM_{10}
Newtownabbey Antrim Road	54.666013, -5.950219	Roadside	NO_X
North Down Holywood A2	54.641963, -5.837939	Roadside	NO_X, PM_{10}
Strabane Springhill Park *(referred to as 'Strabane 2' in the black carbon network)*	54.821427, -7.453291	Urban Background	PM_{10}, SO_2, black carbon
Strathfoyle Bawnmore Place	55.034322, -7.264644	Urban Background	PM_{10}

Figure 2-1 shows the location of the automatic monitoring stations in Northern Ireland.

Figure 2-1 Map of Automatic Air Quality Monitoring Stations in Northern Ireland, 2020



2.3 Statistical Models

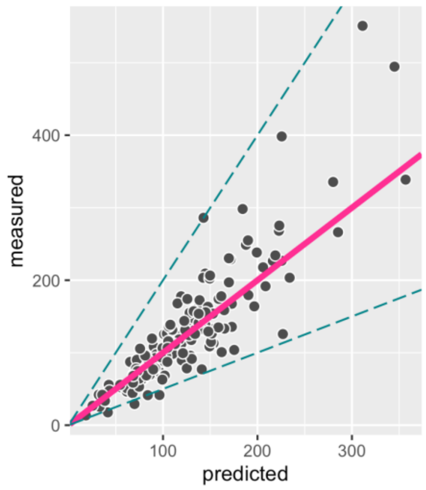
A useful approach is to develop statistical models to set up a "*counterfactual*", i.e. to predict what the concentration of pollutants would have been if Covid-19 had not occurred. Over the years a range of modelling approaches and applications have been developed (Carslaw, D.C. & Taylor, P.J., 2009) (Grange, S.K. et al., 2018) (Grange, S.K. & Carslaw, D.C., 2019). These approaches are example of the application of statistical techniques such as Boosted Regression Trees and Random Forests. Both techniques work well at explaining hourly or daily concentrations of pollutants in terms of commonly measured (or modelled) meteorological data such as wind speed, direction and ambient temperature. In essence, models can be developed and tested over a period and then used to predict concentrations over a new period.

In this case, use was made of the '*deweather*' R package, https://github.com/davidcarslaw/deweather. The models were based on hourly concentration data from the Northern Ireland Air Quality website at https://www.airqualityni.co.uk and meteorological data from the Weather Research and Forecasting (WRF) regional scale model run by Ricardo over the period January 2018 to June 2020. Model variables included basic meteorological measurements such as wind speed, wind direction, ambient temperature and variables to account for the temporal variation in emissions such as (local) hour of the day and day of the week. The models were evaluated against randomly withheld data i.e. data not used for the model development.

An example of model performance is shown in Figure 2-2 for the Belfast Stockman's Lane site for NO_x. The scatter plot and statistics show how well the model performs against data *not used for model development*. The scatter plot compares modelled daily mean NO_x concentrations (for a range of random dates *not* used in the model development) with the actual measured daily mean concentrations. The statistics shown on the right are for data used to build the model, and those on the left show the statistics for data not used to build the model. While there are many model metrics, the most important are mean bias (MB), the correlation coefficient (r) and the Root Mean Squared Error (RMSE). It should be noted that improvements in performance would be expected if surface meteorological data were used in place of modelled data.

In general, for most pollutants, these models do a very good job of predicting concentrations and therefore provided some confidence that the development of a 'Business as Usual' (BAU) was robust.

Figure 2-2 Example of how model performance was tested: measured v predicted daily mean NOx concentrations at the Belfast Stockman's Lane site from 2018 to May 2020



statistic	value
Test data	NA
n	154.00
FAC2	0.97
MB	-6.14
MGE	26.30
NMB	-0.05
NMGE	0.20
RMSE	41.44
r	0.88
COE	0.54
IOA	0.77

statistic	value
Training	NA
n	615.00
FAC2	1.00
MB	-0.33
MGE	19.44
NMB	0.00
NMGE	0.15
RMSE	26.38
r	0.93
COE	0.63
IOA	0.81

Footnote: this figure is provided to ***illustrate the method*** *of testing the model, using real air quality data.*

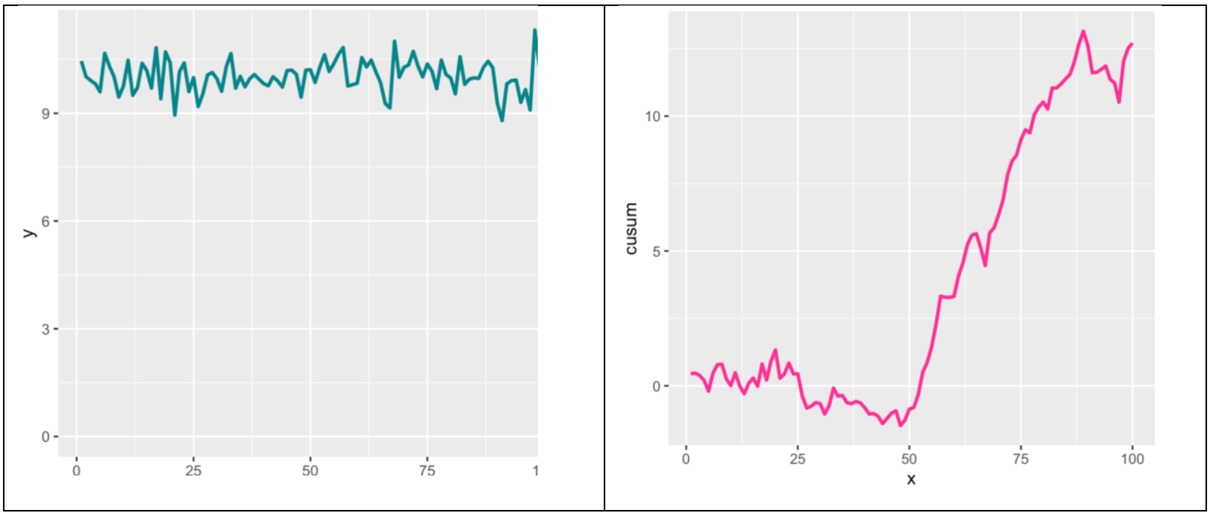
The models were then used to predict hourly concentrations from 1st March onwards at each site. This approach sets up a BAU case where the underlying emissions remain at levels typical of the immediate period pre-lockdown. From 1st March onwards it is therefore possible to compare predicted (i.e. business as usual, the counterfactual) concentrations with actual measured concentrations and consider their differences. Predicting from 1st March allows a period where concentrations did not deviate much from BAU, before social distancing advice (16th March) and start of lockdown (23rd March). It is therefore possible to see at most sites when they deviate from BAU, as described next.

2.4 Cusum Analysis

The analysis in this report also considers how measured concentrations deviate from BAU using a cumulative sum, or **'cusum' analysis**. A cusum analysis accumulates the deviation in concentration from BAU, which helps to highlight possible **change-points** in time series. While the idea is simple, it is effective in the current context because we are considering deviations from the BAU – which should on average be zero if things continue as normal. The approach is especially useful when the changes are small (perhaps at background sites) and where it is very difficult to see a change from the raw data alone.

As an example to illustrate the process, a time series has been generated using random data between 9.5 and 10.5, and halfway through the time series the values increased by adding 0.2, as shown in Figure 2-3. The original time series is shown by the plot of the left of Figure 2-3. It is not clear from this plot when a change may have occurred. But by plotting the cusum of values (right of Figure 2-3), it can be seen there is a clear change in the slope halfway through the time series. The approximately level gradient shown in the first half of the cusum plot shows that values were neither higher nor lower than the average. The positive (and approximately constant) gradient in the second half of the cusum plot shows there was a change in the mean value, roughly halfway through the time series. In fact, if one takes the change in cusum values from halfway through to the end of the time series (about 10 units in this case), and divide by the number of points (50), a value of 0.2 is calculated, which is the average increase in the second part of the time series.

Figure 2-3 Example of a cusum analysis, using random data. Left: a random time series that varies between 9.5 and 10.5 is shown. At t = 50 a value of 0.2 is added to all values between 51 and 100. Right: shows the cumulative sum plot of the accumulated deviations from the mean.



Footnote: this figure is provided as an illustration to explain the method of cusum analysis. It uses randomly generated data, not air quality measurements.

The cusum analysis helps to provide an additional level of inference i.e. not only is a change in concentration calculated, but the timing of that change is considered. Given the Covid-19 situation, one might expect the changes to be closely related to the lockdown date. However, the timing of changes will not be perfect and depend on the random variation that exists in air quality data and the uncertainty of the models used to predict BAU. While not considered here, it is possible to determine whether a change is statistically significant and provide a 95% confidence interval in the timing of the change.

2.5 Openair

The data analysis in this report has made extensive use of Openair: a free, open-source software package of tools for analysis of air pollution data. Openair was developed by King’s College London with the University of Leeds. For more information on this package please see http://www.openair-project.org/ .

3 Review of Emissions

3.1 Overview of Emission Sources in Northern Ireland

When considering the changes to pollutant emissions caused by the lockdown restrictions, it is important to understand the relative importance of the various sources, in terms of their contribution to Northern Ireland’s total emissions. Even if the lockdown restrictions caused large changes in emissions from a particular source, the overall impact would be small if this source only contributed a small proportion of the overall total. This section therefore provides an overview of the most important sources of the pollutants covered by this investigation. It is based on data from the Air Pollutant Inventory Report for England, Scotland, Wales and Northern Ireland (Ricardo Energy & Environment, 2019) using data from the National Atmospheric Emission Inventory (NAEI) (BEIS, 2020). The data are from year 2017 (the most recent year for which Northern Ireland-specific air pollution inventories are available).

Table 3-1 Source Emission Contributions by Sector, Northern Ireland 2017

Sector	NH_3	CO	NOx	PM_{10}	$PM_{2.5}$	SO_2
Agriculture	96%	IE	IE	17%	5%	IE
Energy Industries	IE	4%	15%	1%	2%	19%
Fugitive Emissions	IE	0%	IE	IE	IE	0%
Industrial Combustion	IE	24%	23%	20%	26%	36%
Industrial Processes	0%	0%	IE	12%	3%	0%
Residential, Commercial & Public Sector Combustion	IE	54%	14%	39%	52%	34%
Solvent Processes	IE	0%	0%	0%	0%	0%
Transport Sources	1%	17%	42%	10%	9%	10%
Waste	1%	IE	IE	IE	IE	IE
Other	3%	1%	7%	2%	2%	1%

Footnotes to Table 3.1:

NH_3 = ammonia,

IE = included elsewhere.

'Fugitive emissions' are unintended or accidental releases of a substance, usually from an industrial process. For example, leakage.

'Waste' includes a range of waste treatment processes including biological treatment (such as anaerobic digestion, composting or disposal on land), waste incineration, landfill processes and wastewater handling.

3.1.1 Ammonia

Ammonia (NH_3) is implicated in many environmental processes, including the formation of ammonium sulphate and nitrate particles which contribute to 'secondary' particulate matter. The vast majority (96%) of Northern Ireland's ammonia emissions are from agriculture. Ammonia is outside the scope of this report, but it is briefly mentioned here in the context of its role as a precursor to particulate matter.

3.1.2 Oxides of Nitrogen

Significant sources of NOx in Northern Ireland are Industrial Combustion (23%), Energy Industries (15%) and Residential, Commercial and Public Sector (14%) (Ricardo Energy & Environment, 2019). However, the region's biggest source of NO_X is Transport (42%). Of this 42%, nearly half (46.7%) comes from passenger cars, which therefore account for 19.6% of the region's total NOx emissions. The rest is divided between 'other road vehicles' (23.9% of Transport emissions or 10.0% of the total), and 'rail, aviation and shipping' (29.4% of Transport emissions or 12.3% of the total). Road transport – passenger cars together with other road vehicles - therefore produces an estimated 29.6% of Northern Ireland's total NO_X emissions. Pollution from road transport is believed to be particularly significant from the point of view of health impacts: unlike emissions from most industrial sources, vehicle emissions are produced near ground level, often in urban areas where people are exposed to them (DAERA, 2015).

3.1.3 Ozone

Ozone (O_3) is not included in Table 3.1, as it is not emitted in significant quantities from any sources. As previously explained in section 1.3.2, ozone is mostly formed in the atmosphere from reactions between other compounds including VOCs and NO_X, in the presence of sunlight and heat. It is also removed from the atmosphere by reaction with nitric oxide (NO), so ambient concentrations of NO can have an effect on concentrations of ozone.

3.1.4 PM_{10} and $PM_{2.5}$

The 'Residential, Commercial and Public Sector' category accounts for the highest proportion of Northern Ireland's PM_{10} and $PM_{2.5}$ emissions. Industrial Combustion and Transport are also important sources. For PM_{10}, Agriculture and Industrial Processes are also important. However, Energy Industries (which include power generation) contribute only 1% and 2% of PM_{10} and $PM_{2.5}$ emissions respectively.

It is also important to note that not all ambient particulate matter is 'primary' i.e. directly emitted from source. There is also a significant contribution from 'secondary' particulate matter such as particulate sulphate and nitrates, produced from reactions in the atmosphere. Some particulate matter also comes from natural sources such as suspended soil, dust and sea salt.

3.1.5 Sulphur Dioxide

Sulphur dioxide is produced from the combustion of fuels containing sulphur impurities, such as coal and oil. In Northern Ireland the most significant emission sources are Industrial Combustion, the 'Residential, Commercial and Public Sector' category, Energy Industries (in this case, 100% of which is power generation), and transport sources.

3.1.6 Carbon Monoxide

Over half of Northern Ireland's carbon monoxide (CO) emissions arise from combustion in the 'Residential, Commercial and Public Sector' category. The Air Pollutant Inventory Report for England, Scotland, Wales and Northern Ireland (Ricardo Energy & Environment, 2019) 'disaggregates' these, showing that of this sector, 93% is residential combustion. Industrial Combustion (24%) and Transport (17%) are also significant sources.

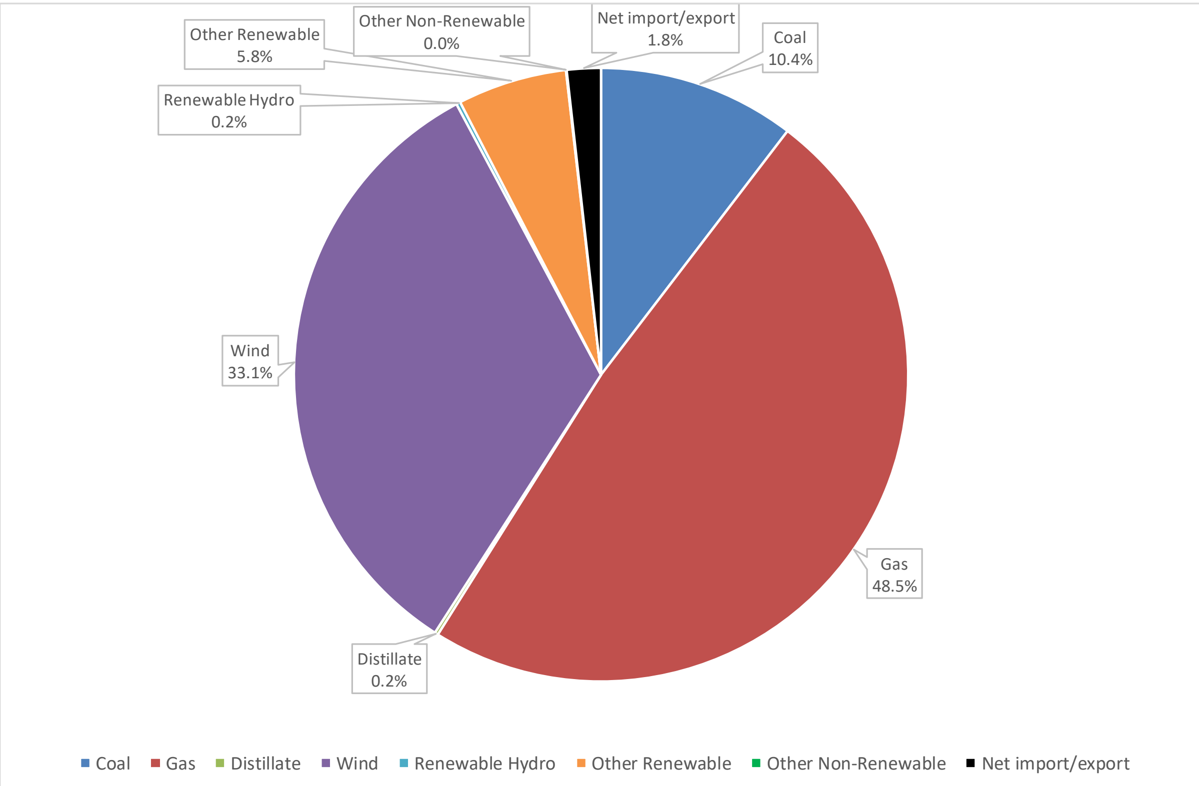
3.2 Assessment of Changes in Emissions

3.2.1 Power Generation and Consumption

3.2.1.1 Power Generation Sources

Northern Ireland's electricity comes from a range of sources, illustrated as a pie chart in Figure 3-1. (This shows the 2019 annual totals.) These data come from Northern Ireland's transmission grid operator, SONI Ltd. and were supplied to DAERA by the Department for the Economy (DfE) .

Figure 3-1 Power Generation in Northern Ireland, 2019 (Source: SONI Ltd)



In 2019, fossil fuels, natural gas and coal accounted for 48.5% and 10.4% of Northern Ireland's power generation respectively. A small percentage (0.2%) was produced by combustion of fuel oil (referred to as 'distillate'). 33.1% was generated by wind power: 5.8% came from other renewables, which include photovoltaic (i.e. solar), biomass, biogas and landfill gas. Northern Ireland also imports energy from, and exports energy to, the Republic of Ireland and Great Britain. In 2019 Northern Ireland was a net importer of energy, with 1.8% being generated outside the region. For comparable information on power generation in the UK as a whole, please refer to the Department for Business, Energy and Industrial Strategy (BEIS) document, 'UK Energy in Brief 2020' (BEIS, 2020).

It is the fossil fuel burning – coal and gas – that are of relevance to this investigation. Northern Ireland has four large fossil fuel power stations:

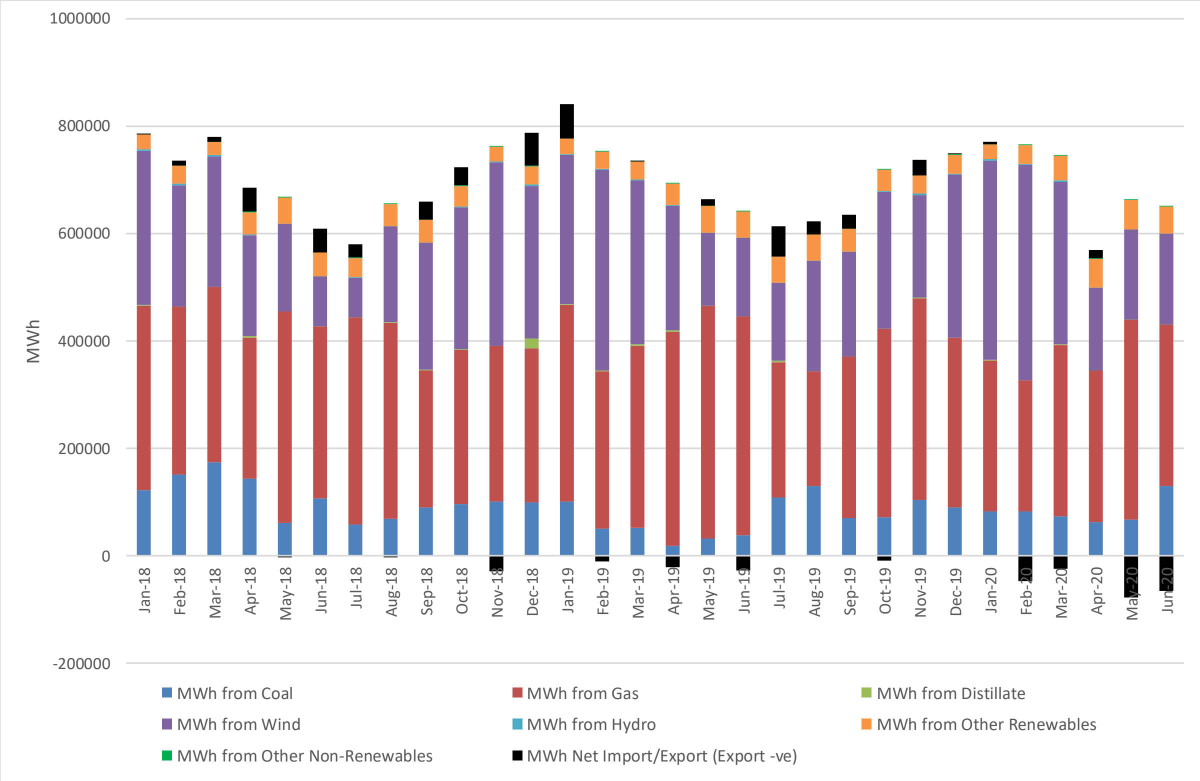
- Kilroot near Carrickfergus (700 MW), main fuel is coal.
- Ballylumford, near Larne (600 MW), main fuel gas.
- Coolkeeragh near Derry/Londonderry (400 MW), main fuel gas.
- Moyle, Antrim (450 MW), gas.

3.2.1.2 Changes to Electricity Demand During Lockdown

Electricity demand data provided by the Department for the Economy is used below to show how power generation changed during the lockdown period.

Figure 3-2 shows Northern Ireland's monthly electric energy demand, in megawatt hours (MWh), split between the various sources, for months January 2018 to June 2020. (Note that the net import/export from outside Northern Ireland – shown in black - is sometimes positive and sometimes negative, depending on whether Northern Ireland was a net importer or exporter of power in any given month. When negative it appears at the bottom of the column, below the x-axis).

Figure 3-2 Monthly Electricity Demand in Northern Ireland Jan 2018 - Jun 2020, MWh



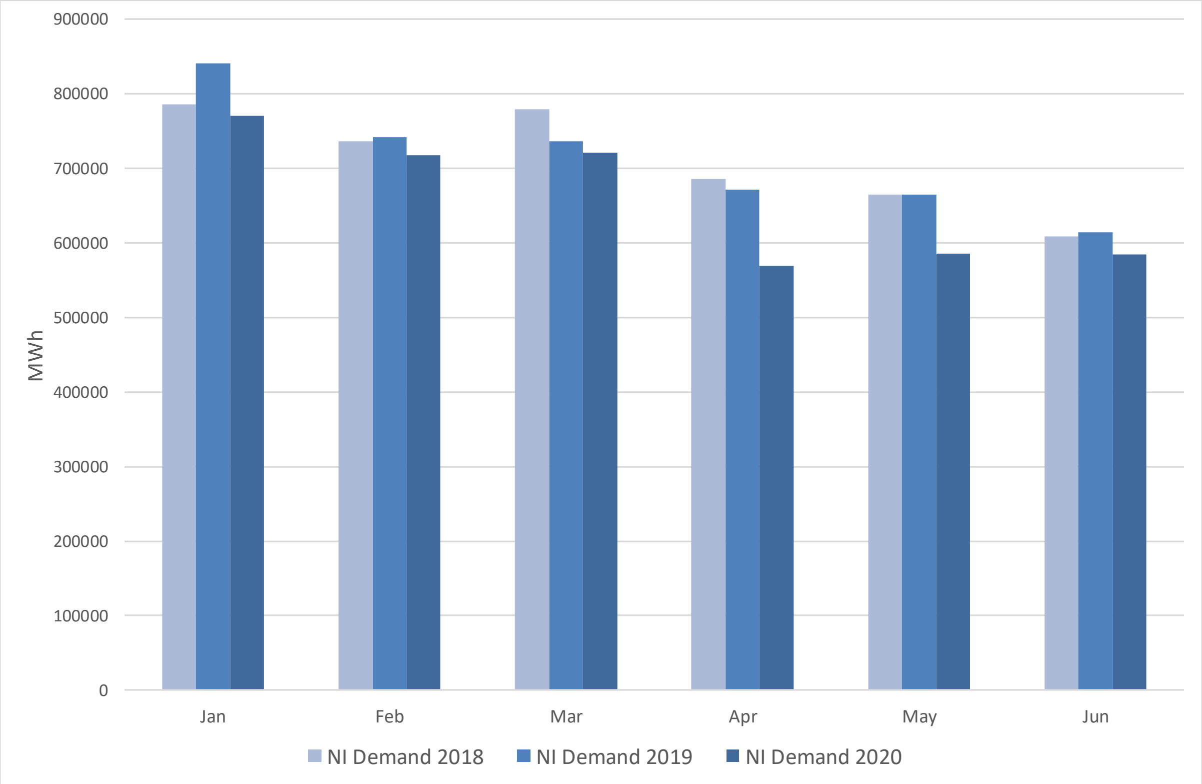
There is a marked dip in energy demand in the month of April 2020. This is further illustrated by Figure 3-3, which compares total monthly electricity demand in months January to June, for years 2018 to 2020. Demand in each one of the first six months of 2020 was slightly lower than in the corresponding month in 2018 and 2019: this could be for many reasons, for example weather conditions at the time. However, the difference appears marked in the case of April, and to a lesser extent, May.

As an approximate estimate, Northern Ireland's electricity demand appears to have been reduced during May and June 2020 as follows:

- April 2020: 569,150 MWh compared to a mean of 678,774 MWh for the previous two Aprils – a reduction of 16%.
- May 2020: 585,447 MWh compared to a mean of 664,930 MWh for the previous two Mays – a reduction of 12%.
- June 2020: 584,742 MWh compared to a mean of 611,325 MWh for the previous two Junes – a reduction of 4%.

As demand in January, February and March 2020 was also down by between 3-5% compared to the corresponding months in 2018 and 2019, it is reasonable to infer that about 4% of the reduction seen in April and May 2020, and the reduction seen in June, was due to non-Covid related factors. The actual reductions in demand not due to this year-on-year decrease are therefore estimated as approximately 12% in April 2020 and 8% in May 2020, with demand returning to normal in June 2020.

Figure 3-3 Monthly Total Electricity Demand in Northern Ireland, Jan-Jun Comparing 2020 with 2018-2019

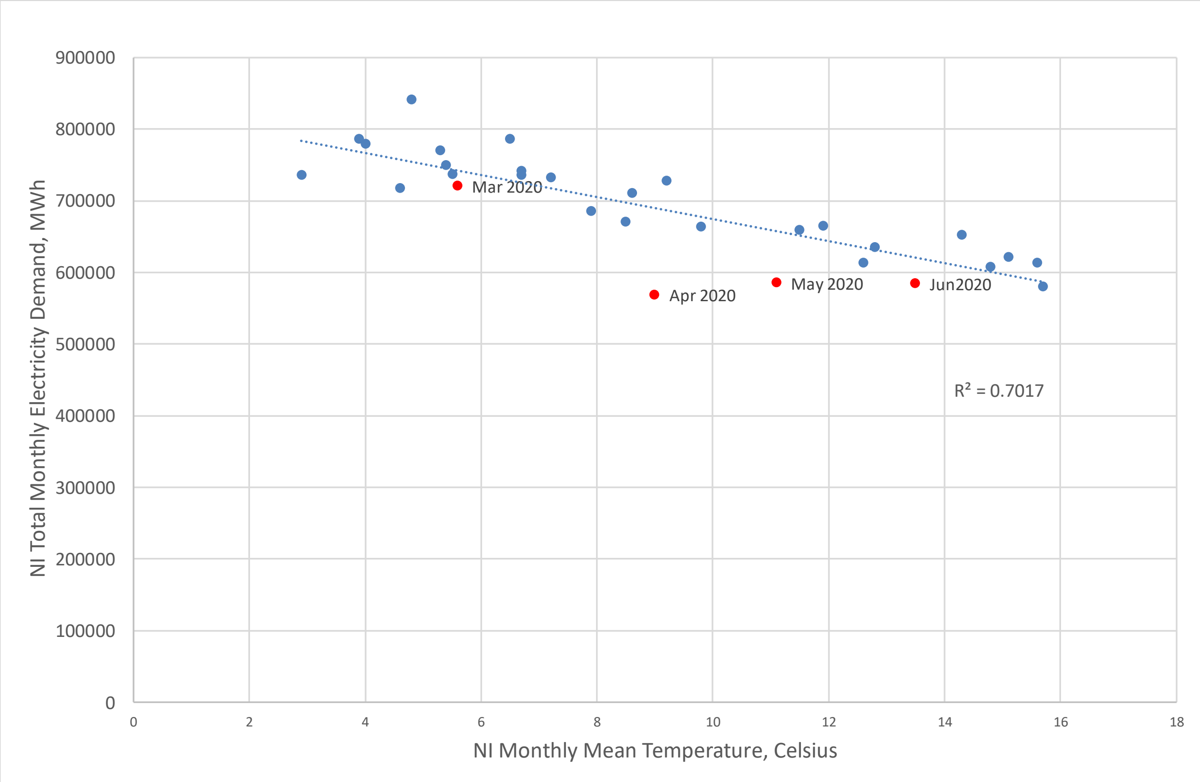


To see whether or not seasonal weather changes could account for changes in energy consumption, it is also relevant to look at the relationship between mean ambient temperature in Northern Ireland (°C) and electricity demand (MWh), illustrated as a scatter plot in Figure 3-4.

Electricity demand is typically negatively correlated with mean ambient temperature, with greater power usage in the colder (and darker) winter months.

The months potentially affected by lockdown are shown as red dots. If demand in March, April, May and June 2020 were following the relationship to monthly temperatures, the dots for these months would be close to the line. However, the dots for April 2020, and to a lesser extent May 2020, are well below the line. These months are therefore showing a lower demand than would be expected on the basis of the average ambient temperature in Northern Ireland in those months. It is therefore concluded that the reductions in electricity demand seen in April and May 2020 were not temperature-driven.

Figure 3-4 Scatter Plot of NI Total Monthly Electricity Demand v Mean Ambient Temperature, Jan 2018 - Jun 2020.



It is therefore concluded that the Covid lockdown resulted in a decrease in Northern Ireland's electricity demand of approximately 12% in April 2020 and 8% in May 2020 compared to what would have been expected without the pandemic.

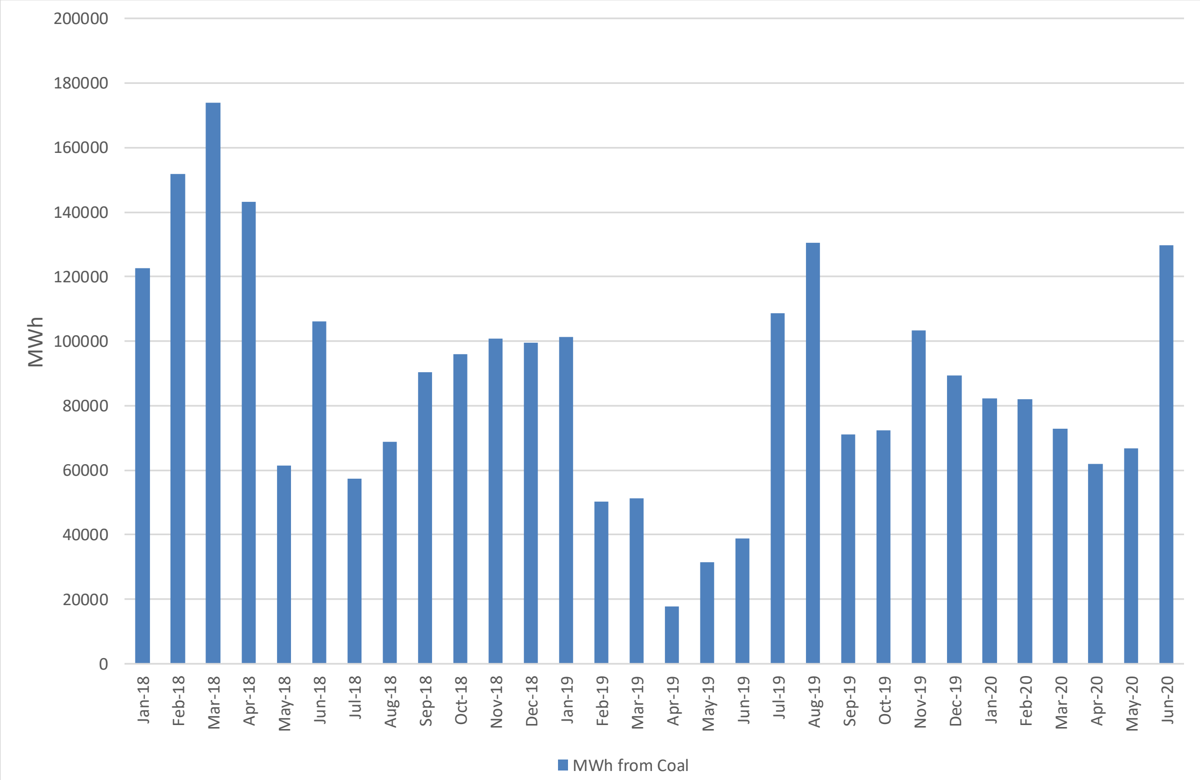
3.2.1.3 Impact of Lockdown on Emissions from Power Generation

Energy generation in Northern Ireland accounts for 19% of the region's SO_2 emissions and 15% of the region's NO_X emissions (see Table 3-1 above). However, this sector accounts for just 4% of CO emissions, 1% of primary PM_{10} emissions and 2% of primary $PM_{2.5}$ emissions. Therefore changes in power generation during lockdown are unlikely to have substantially impacted emissions of pollutants other than SO_2 and NO_X.

SO_2: power generation gives rise to an estimated 19% of Northern Ireland's SO_2 emissions (see Table 3-1). It might therefore be concluded that, for example, the lockdown resulted in a reduction in Northern Ireland's SO_2 emissions of 12% x 19% = 2.3% in April 2020. However, this would be simplistic as it does not it take account of the mix of sources used to generate the power, of which some – but not others – emit SO_2.

In the case of SO_2, in Northern Ireland, coal-fired power generation is the most significant source within the energy production sector. Natural gas combustion produces relatively little SO_2, and wind and hydro-electric plant produce negligible SO_2. Reductions in use of these sources would not significantly affect SO_2 emissions, if coal usage remained the same. Figure 3-5 shows how much energy was generated per month from coal alone over the period January 2018 to June 2020.

Figure 3-5 Monthly Electricity from Coal Alone, Northern Ireland Jan 2018 - Jun 2020, MWh

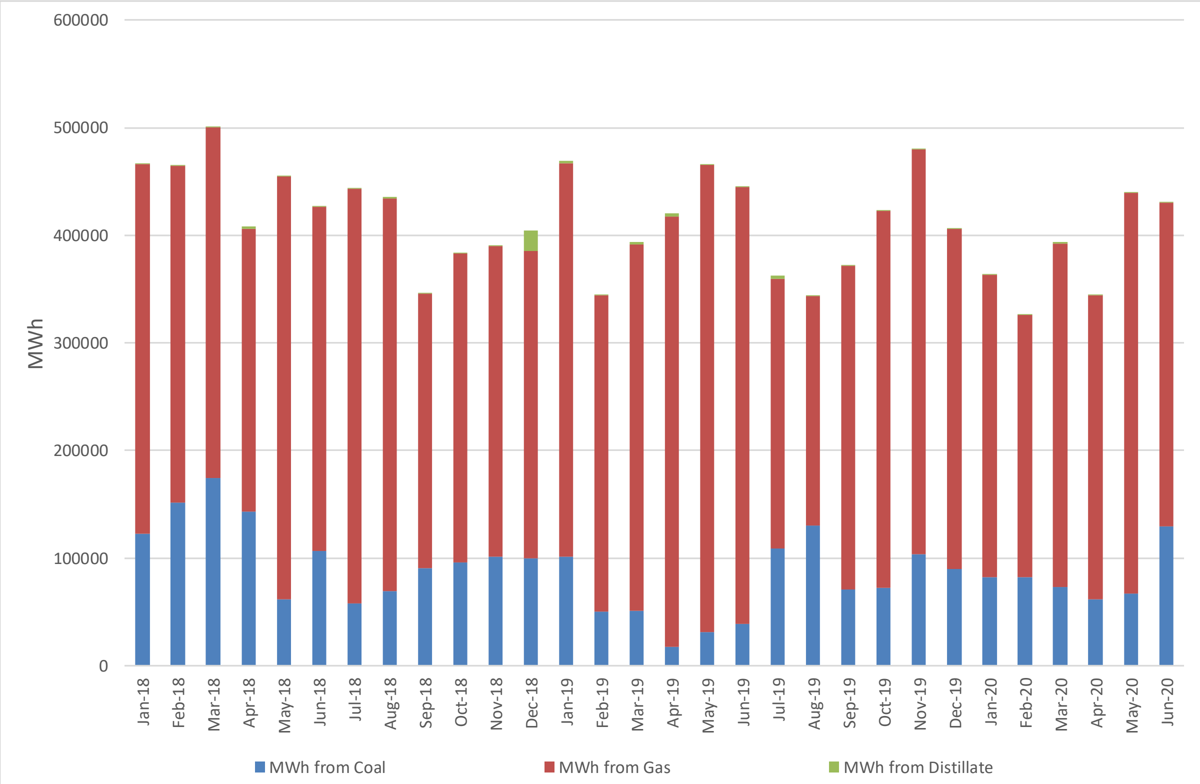


The monthly total MWh generated from coal in April and May 2020, while below the mean, were not anomalously low in the context of this 2 ½ year period. It is therefore estimated that the reduction in Northern Ireland's total SO_2 emissions, as a result of changes in power generation due to the Covid-19 lockdown restrictions in April and May 2020, is likely to have been small, probably less than 1%.

(It is also evident from the graph that in June 2020, the amount of energy generated from coal was the highest since August the previous year. SONI explained this is because they use a system called 'Transmission Constraint Groups' to manage the hours the Ballylumford units operate, between scheduled maintenance. As a result, the coal-fired Kilroot plant was generating more during June.)

NO_X: power generation gives rise to 15% of Northern Ireland's total emissions of NO_X (see Table 3-1). NO_X is emitted from almost all combustion processes, including those burning coal, oil and gas, as well as some of the fuels used in the 'Other Renewables' category – biomass, biogas and landfill gas. (No information is available on how much of the 'Other Renewables' category is made up by non-combustion processes e.g. photovoltaic generation.) Figure 3-6 shows the monthly energy generated in Northern Ireland from coal, gas and oil: the total for April 2020 is lower than average, though higher than in February the same year, before lockdown.

Figure 3-6 Monthly Electricity from Coal, Gas and Oil, Northern Ireland Jan 2018 - Jun 2020, MWh



Using the power generation data provided by SONI, together with NO_X emission factors from the NAEI database at https://naei.beis.gov.uk/data/emission-factors, estimates have been made of monthly total NO_X from power generation in Northern Ireland. The emission factors used are shown in Table 3-2 and relate to 2018, the most recent year for which data are available.

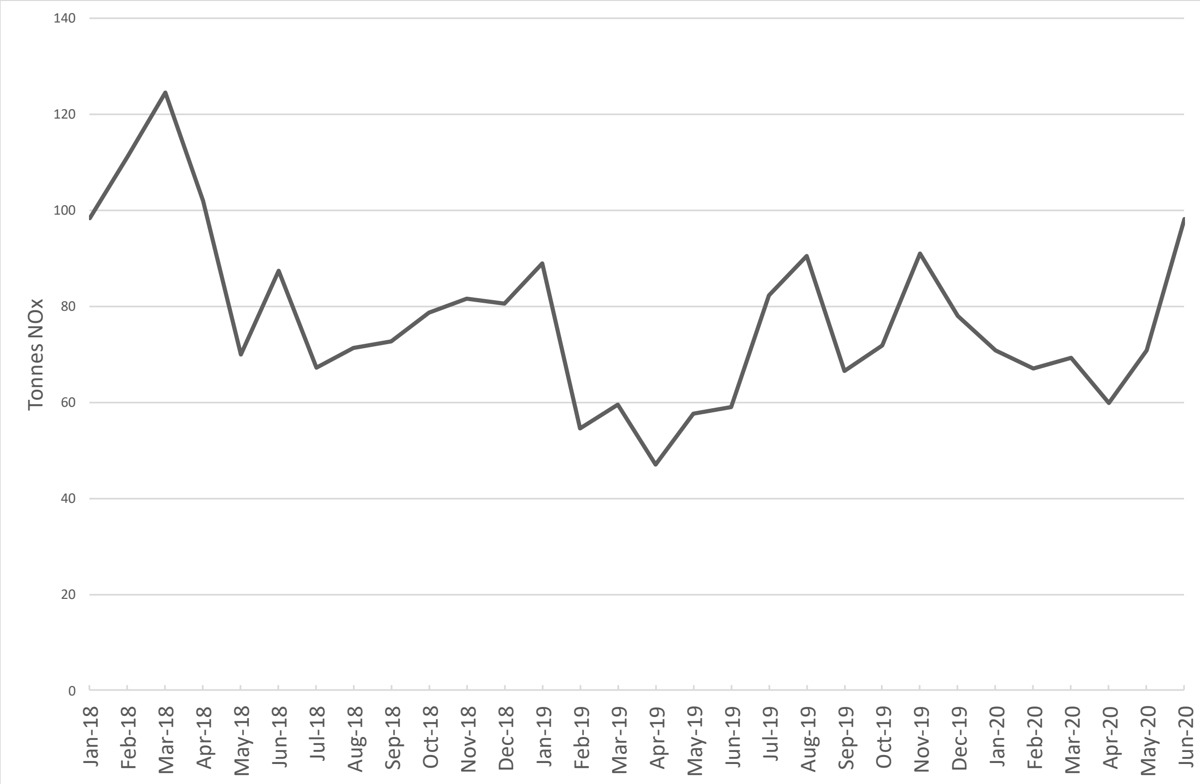
Table 3-2 Emission Factors for Power Stations, 2018 (Source: NAEI)

Pollutant and Fuel (for Power Stations)	kt per TJ	tonnes per MWh
NO_X from Coal	0.00015	5.40E-04
NO_X from Gas	0.000026	9.36E-05

Figure 3-7 shows the estimated monthly total tonnes of NO_X emitted from coal- and natural gas-fired power stations in Northern Ireland during the period Jan 2018 – Jun 2020. These have been calculated on the basis of the emission factors from the NAEI database, and the energy data provided by SONI. Only coal and gas are shown: the NAEI database has no figures for oil (which in any case made up a very small contribution). ‘Other renewables’ are not included as these comprise a mix of combustion sources (such as biomass) and non-combustion sources (such as solar power) and no information is available on the relative proportions.

The mean mass of NO_X emitted is 77.6 tonnes per month. The estimated emissions for April 2020 (59.9 tonnes) and May (70.9 tonnes) are below the mean, but higher than the estimates for months January to June 2019. It therefore appears that estimated NO_X emissions from Northern Ireland’s power stations for April and May 2020 were low, but not anomalously so.

Figure 3-7 Estimated Monthly NO_X Emissions from Coal- and Gas-Fired Power Generation in Northern Ireland (tonnes)



In summary, the conclusions regarding the impact of lockdown on emissions from power generation in Northern Ireland are as follows:

- The lockdown restrictions appear to have caused a drop of approximately 12% in energy generation in April 2020 and approximately 8% in May 2020, with a return to normal in June 2020.
- The dip in demand does not appear to be the result of warm weather.
- Although total electricity demand and generation dipped in April and May 2020, the amount produced using coal, oil and gas were not unusually low.
- It is therefore estimated that any reduction in pollutant emissions during this period was small: probably less than 1% of the Northern Ireland total in the cases of both SO_2 and NO_X.

3.2.2 Domestic Fuel Burning

Domestic fuel burning is not monitored or measured. It has therefore been necessary to make assumptions about how domestic fuel burning may have changed during the lockdown period.

It is reasonable to hypothesize that domestic fuel burning may have increased in the early part of the lockdown period (from 23rd March to the end of the month) as more people were at home during the daytime when they would normally have been at their workplaces. This coincided with a period of relatively cold weather. April and May 2020 were warmer on average than March 2020 (see section 4), approaching the summer when most people would normally turn off their heating.

Any increase in domestic fuel burning would likely have been offset by a decrease in fuel use at shops, schools, restaurants and business premises which may have been closed for part of the lockdown period or operating for reduced hours. However there is insufficient information to quantify this.

3.2.3 Road Transport

Traffic flow data from fourteen traffic count points across Northern Ireland was provided by the Department for Infrastructure for identifying changes in traffic numbers and comparison with the air quality measurements.

The datasets consist of daily counts of vehicle numbers (for each vehicle type and total counts) for the locations given in Table 3-3. A map showing the location of each site is provided in Figure 3-8.

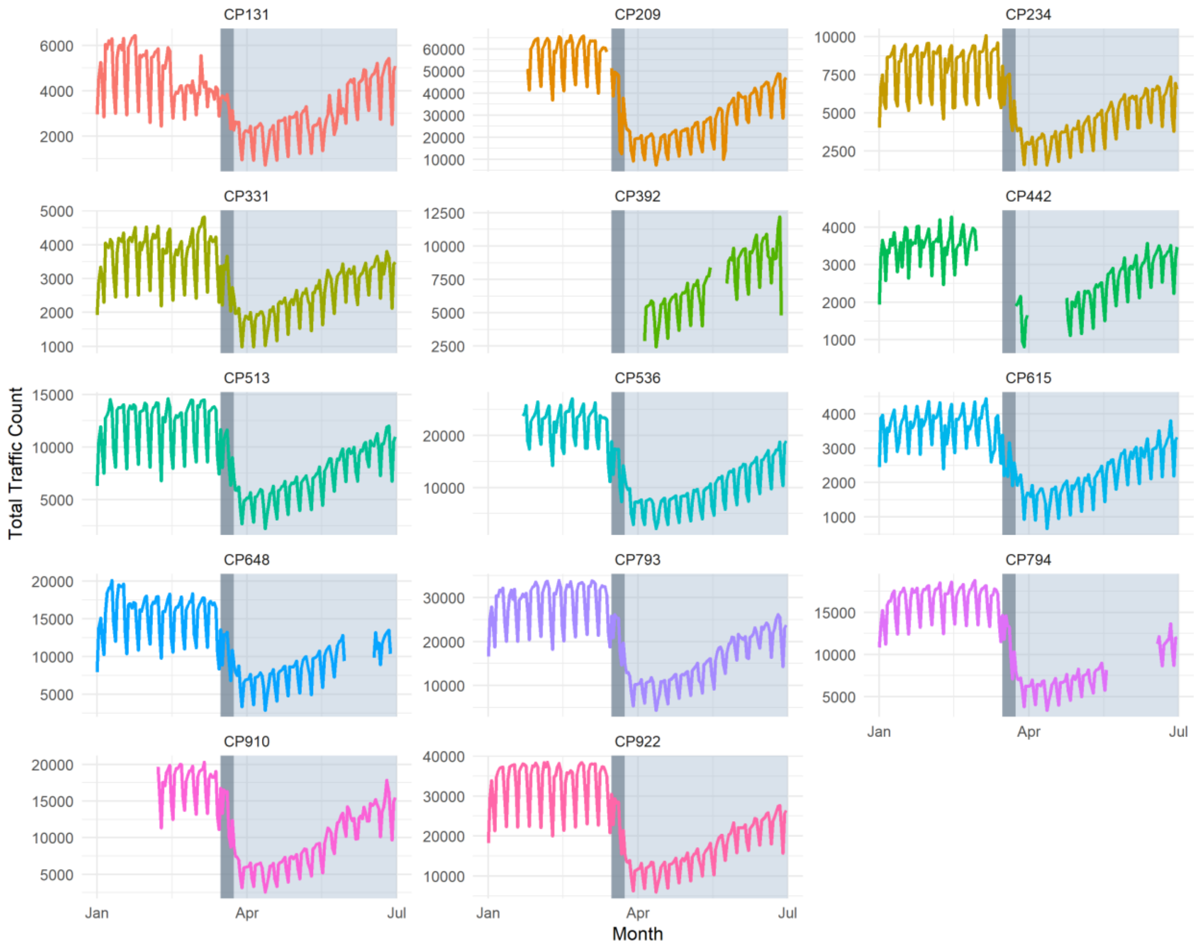
Table 3-3 Locations of the traffic counts provided for this study

Count Point Number	Route	Location	Latitude	Longitude
131	A36	Ballymena-Larne, at Moorfield	54.8403	-6.2068
209	A2	Sydenham By-Pass, at George Best Belfast City Airport	54.6102	-5.8759
234	B101	Pond Park Road, Lisburn	54.5358	-6.0731
331	B64	Dungiven-Garvagh, at Dungiven	54.9321	-6.9188
392	A2	Duke Street, Londonderry	54.9916	-7.3130
442	A3	Monaghan Road, Middletown, Co Armagh	54.2923	-6.8081
513	A7	Belfast Road, Downpatrick, at Quoile	54.3373	-5.7241
536	A1	A1 Newry, North of A27 Junction	54.2108	-6.3570
615	A4	Enniskillen-Belcoo (East of Letterbreen near Moybrone/ Station Road Cross Roads)	54.3125	-7.7158
648	A5	Strabane By-Pass (Barnhill Road West of Derry Road)	54.8373	-7.4600
793	A2	Shore Road South of Jordanstown Road	54.6802	-5.8861
794	A1	Lisburn Road at Dunluce Avenue	54.5846	-5.9421
910	A2	Bangor Road, Cultra, before Whinney Hill	54.6479	-5.8104
922	A55	Knock Road, Castlereagh, at Shandon Park	54.5825	-5.8642

Figure 3-8 Locations of Traffic Count sites

Figure 3-9 shows the **daily total vehicle counts** for the 14 locations from 1st Jan 2020 – 30th Jun 2020. The unshaded region indicates the period before restrictions began on 16th March: the (narrow) darker shaded region indicates the period when social distancing measures were implemented (March 16th) and the lighter shaded region when lockdown began (March 23rd).

Figure 3-9 Daily Total Vehicle Counts



These graphs show that total traffic counts began to fall sharply around the point at which social distancing began. The decrease in traffic count varied from site to site, but typically traffic counts dropped to around one third of usual levels at the lowest point, which in most cases was in early April. Traffic then gradually increased through later April, May and June. However, there is some evidence of long-term reductions in traffic counts, as even by the beginning of July, traffic counts had not returned to their pre-lockdown levels.

The vehicle counts were also summed over weekly periods to give totals for each vehicle type. Figure 3-10 to Figure 3-23 provide a breakdown of vehicle counts by vehicle type, for each site and week.

The weeks are numbered according to the ISO system of week numbering, with weeks beginning on Mondays and week 1 being the week in which 1st Jan falls. Week 1 is week beginning Monday 30th Dec 2019. Social distancing began in week 12 of the year (beginning Mon 16th Mar) and lockdown in week 13 (beginning Mon 23rd Mar). Note: only the weeks that contained seven full days of data capture are included here.

In these graphs, ‘Artic’ denotes an articulated HGV, ‘Car + T’ is a car plus trailer, ‘Mcl’ is a motorcycle, and ‘Rigid’ is a rigid i.e. non-articulated HGV.

Figure 3-10 Weekly Traffic Numbers by Vehicle Type, Count Point 131 (A36 Ballymena - Larne). The arrow indicates when lockdown started (week 13).

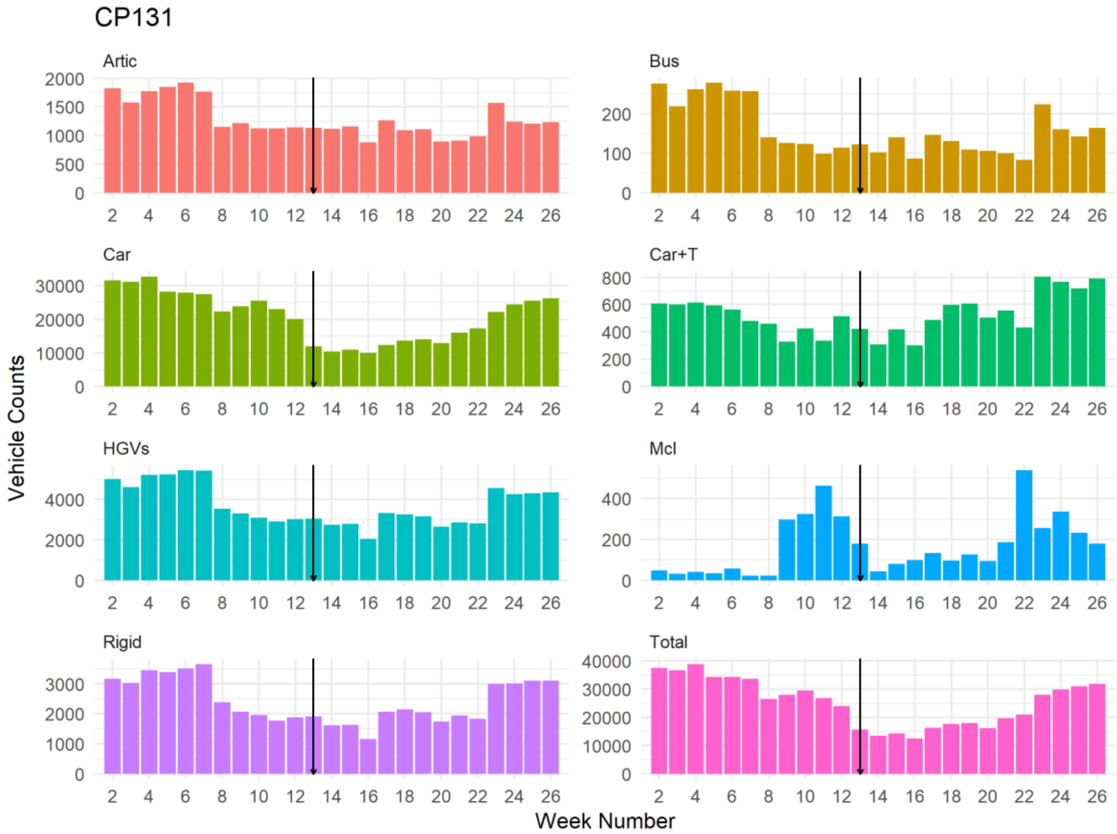


Figure 3-11 Weekly Traffic Numbers by Vehicle Type, Count Point 209 (A2 Sydenham Bypass)

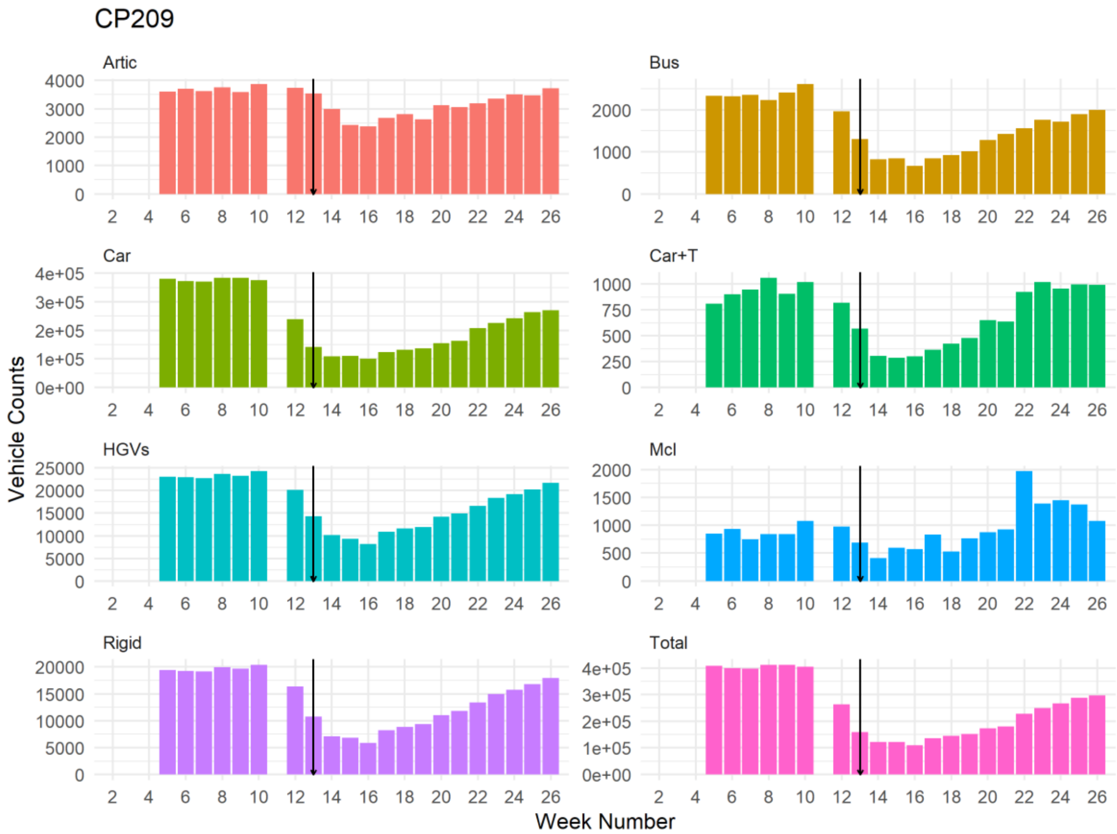


Figure 3-12 Weekly Traffic Numbers by Vehicle Type, Count Point 234 (B101, Lisburn)

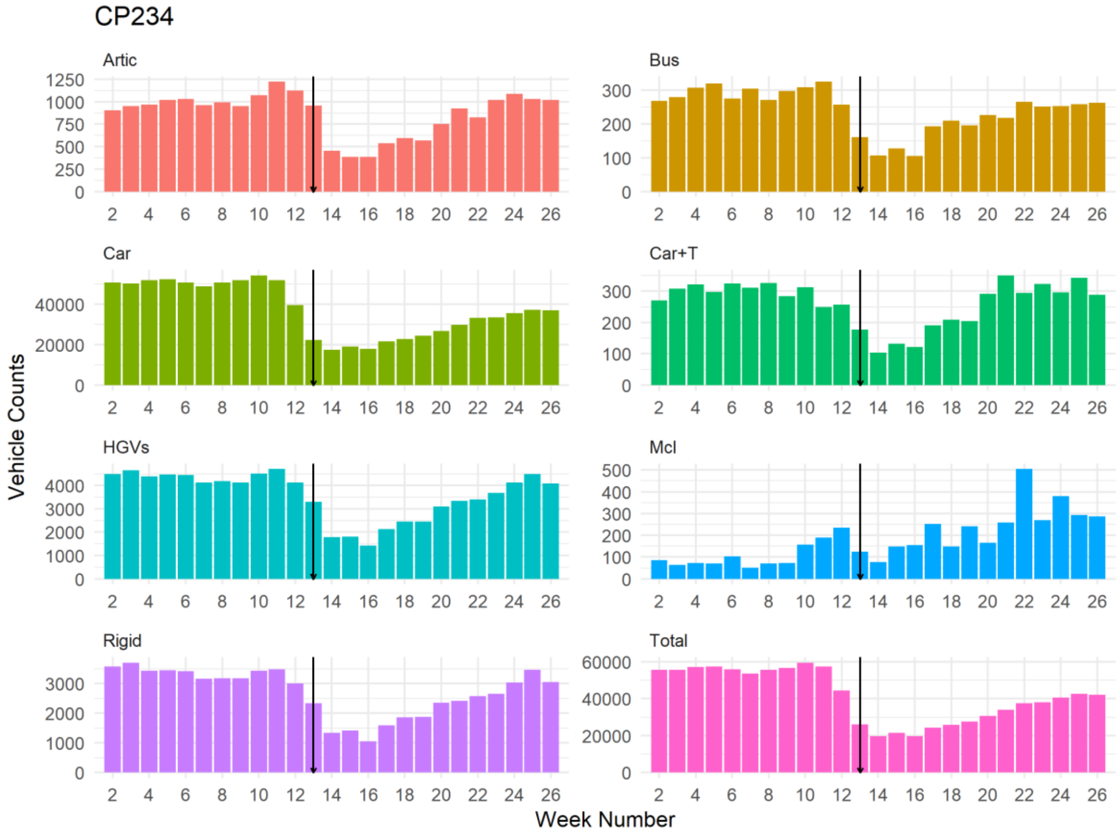


Figure 3-13 Weekly Traffic Numbers by Vehicle Type, Count Point 331 (B64, Dungiven)

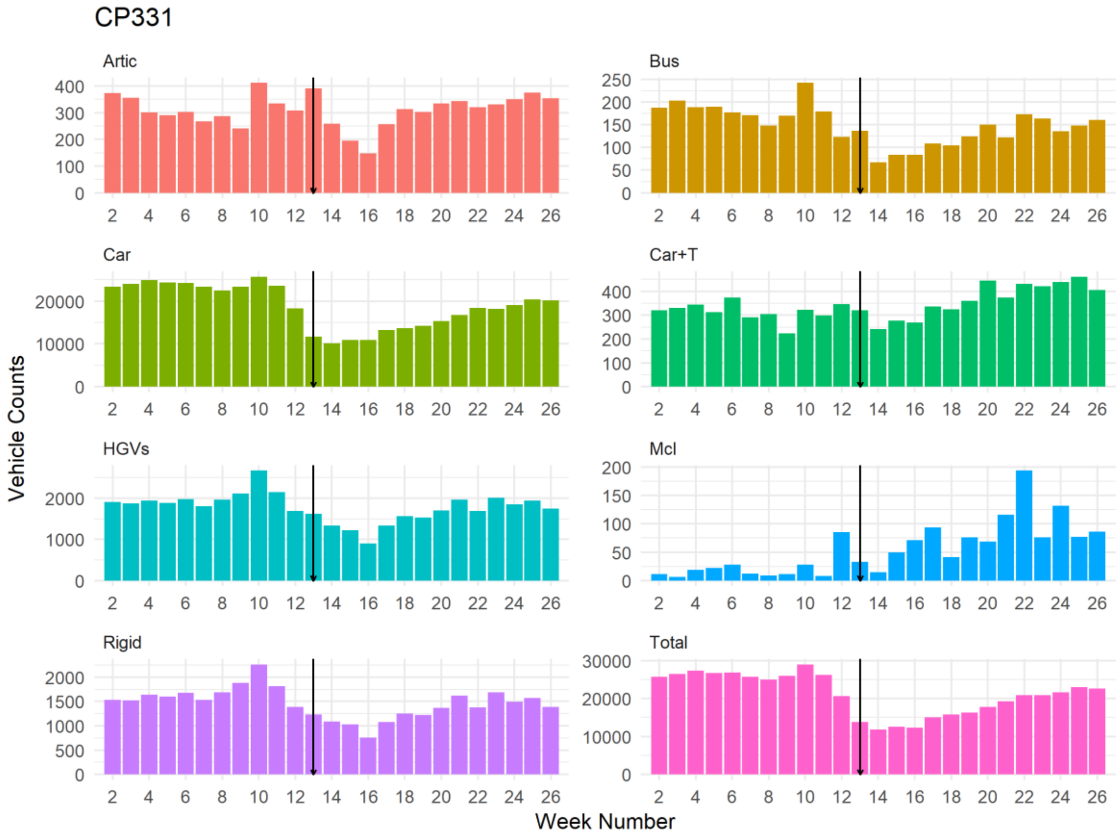


Figure 3-14 Weekly Traffic Numbers by Vehicle Type, Count Point 392 (Duke St, Derry/Londonderry)

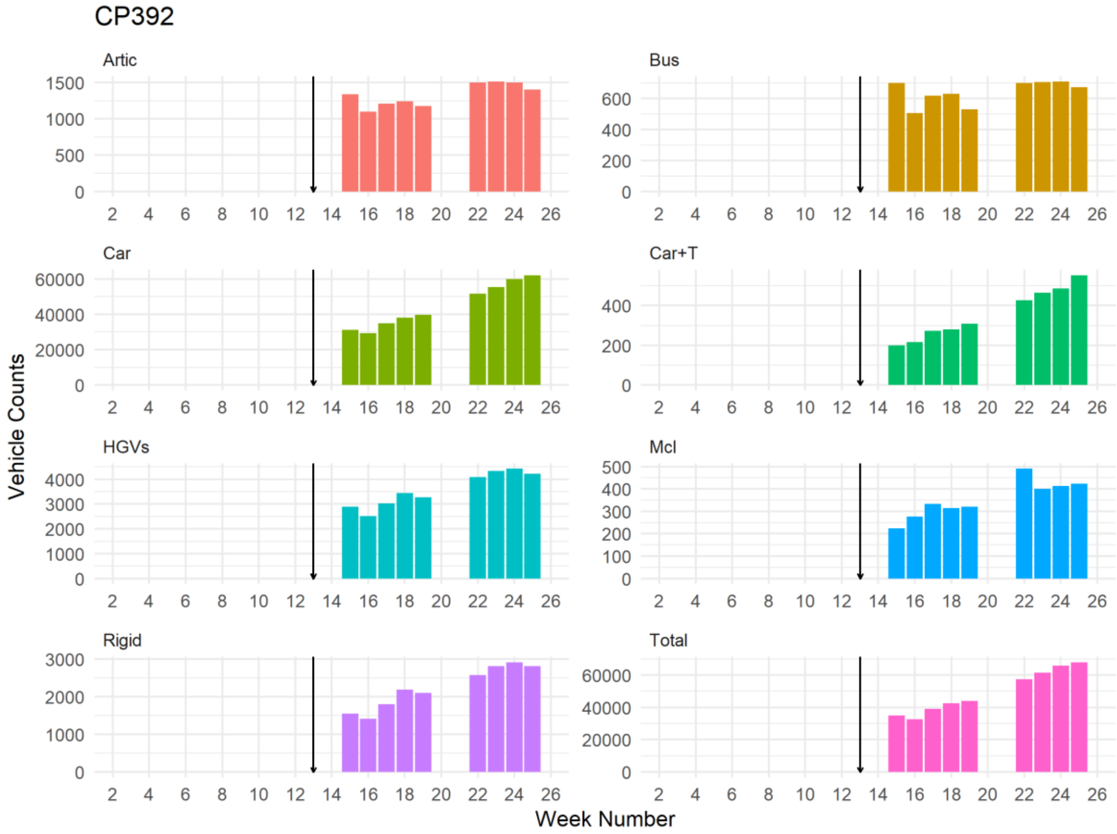


Figure 3-15 Weekly Traffic Numbers by Vehicle Type, Count Point 442 (A3, Middletown)

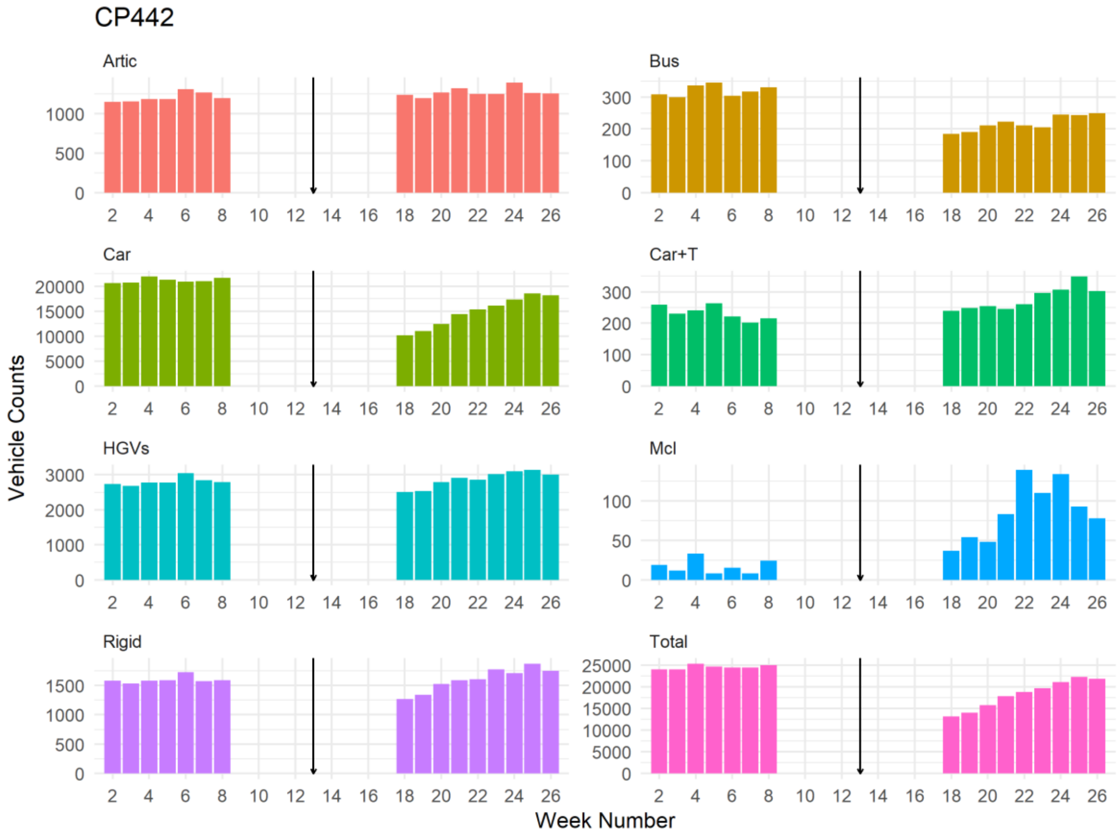


Figure 3-16 Weekly Traffic Numbers by Vehicle Type, Count Point 513 (A7, Downpatrick)

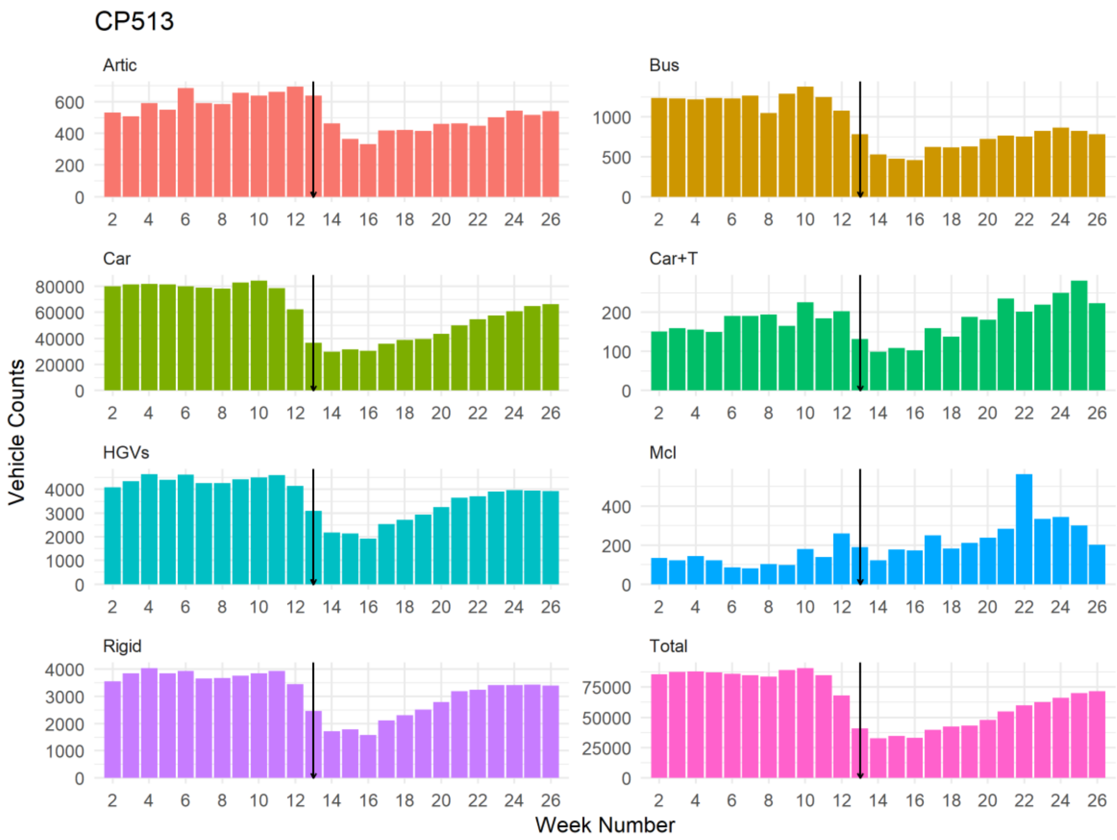


Figure 3-17 Weekly Traffic Numbers by Vehicle Type, Count Point 536 (A1, Newry)

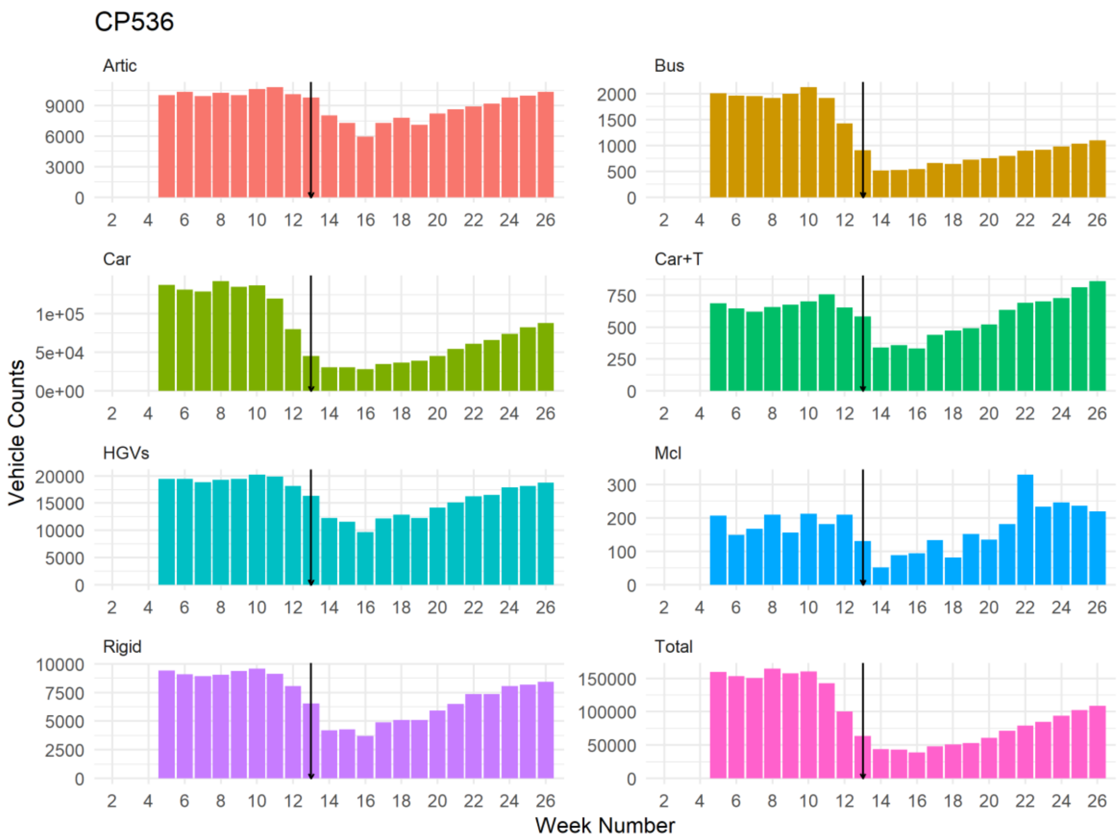


Figure 3-18 Weekly Traffic Numbers by Vehicle Type, Count Point 615 (A4, Enniskillen to Belcoo)

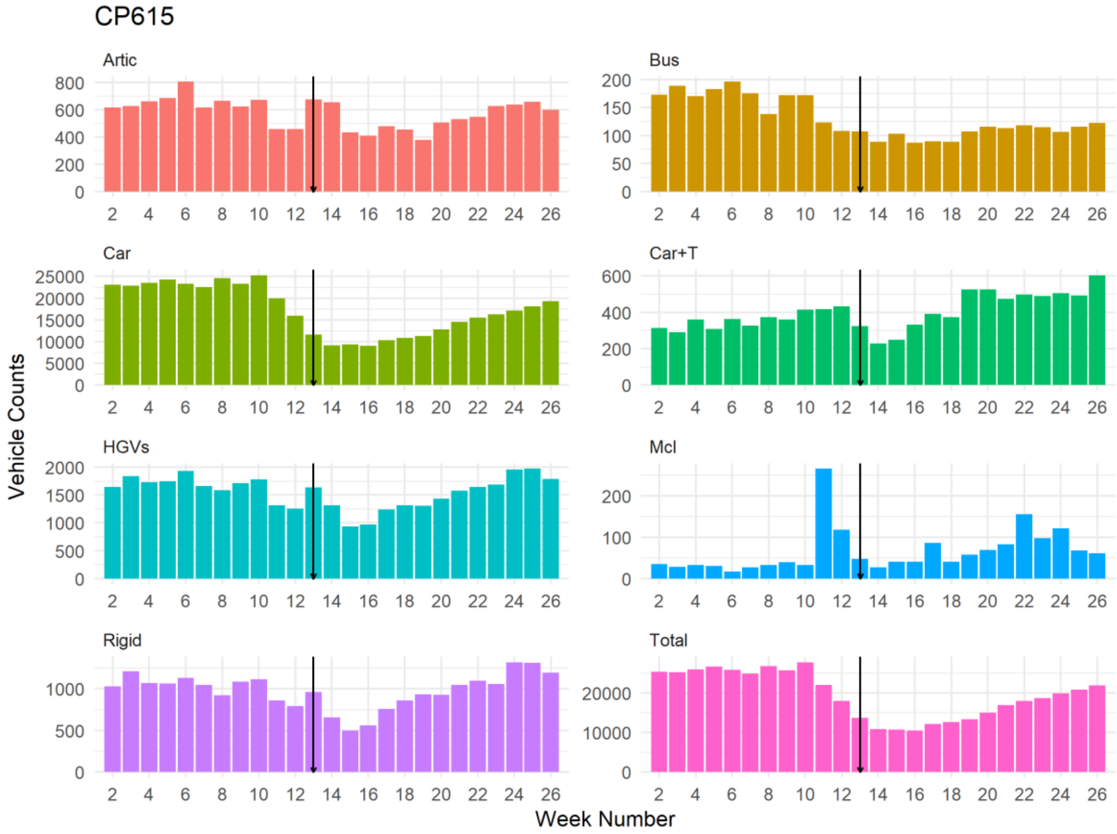


Figure 3-19 Weekly Traffic Numbers by Vehicle Type, Count Point 648 (A5 Strabane Bypass)

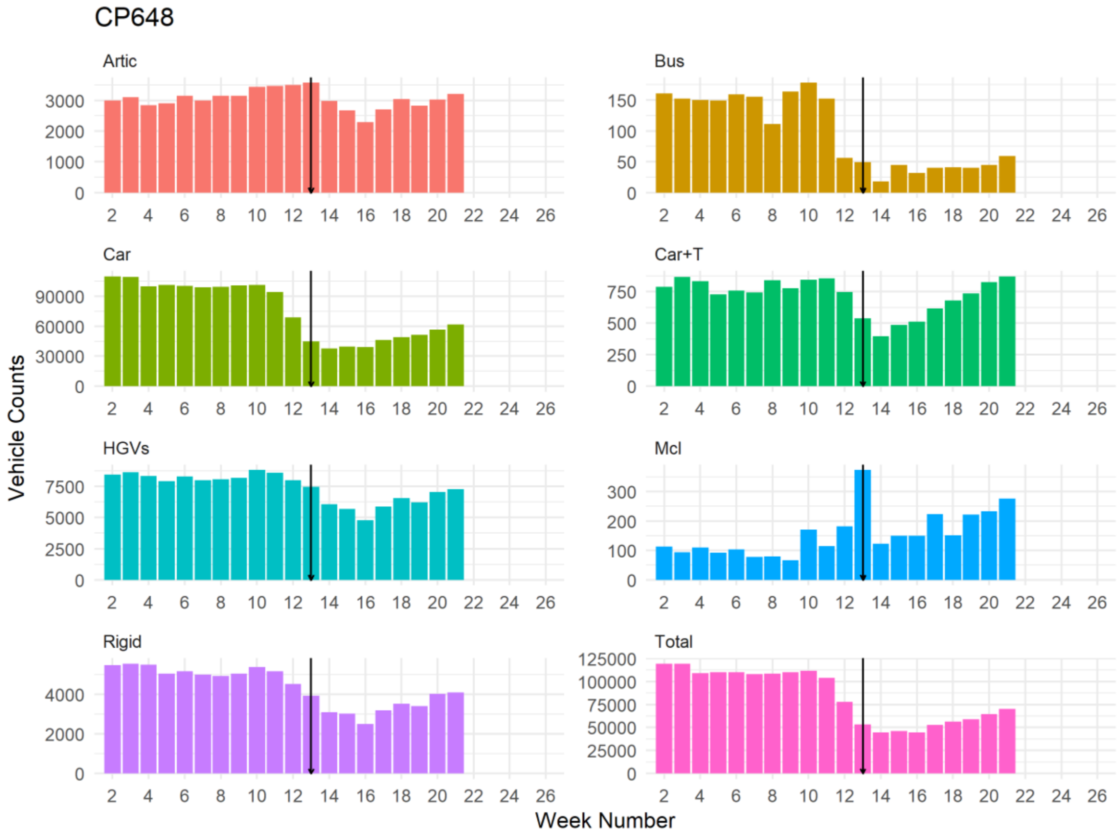


Figure 3-20 Weekly Traffic Numbers by Vehicle Type, Count Point 793 (A2 Shore Road)

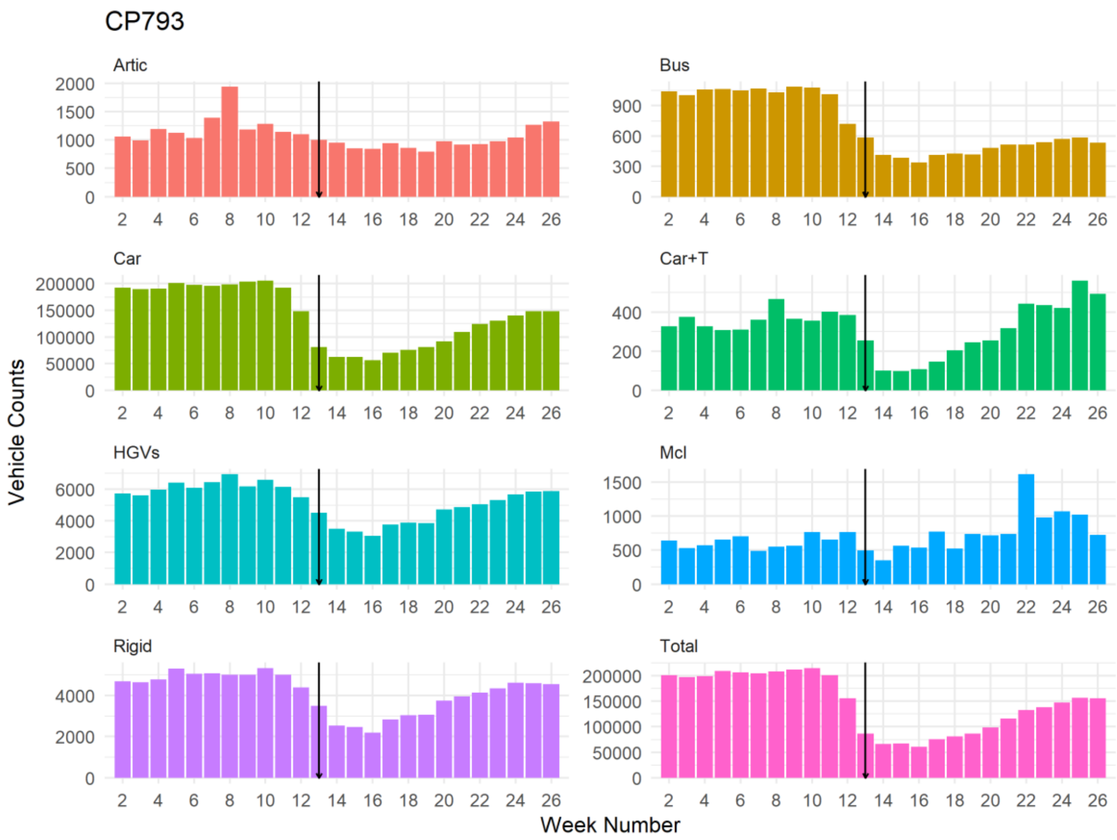


Figure 3-21 Weekly Traffic Numbers by Vehicle Type, Count Point 794 (A1 Lisburn Road)

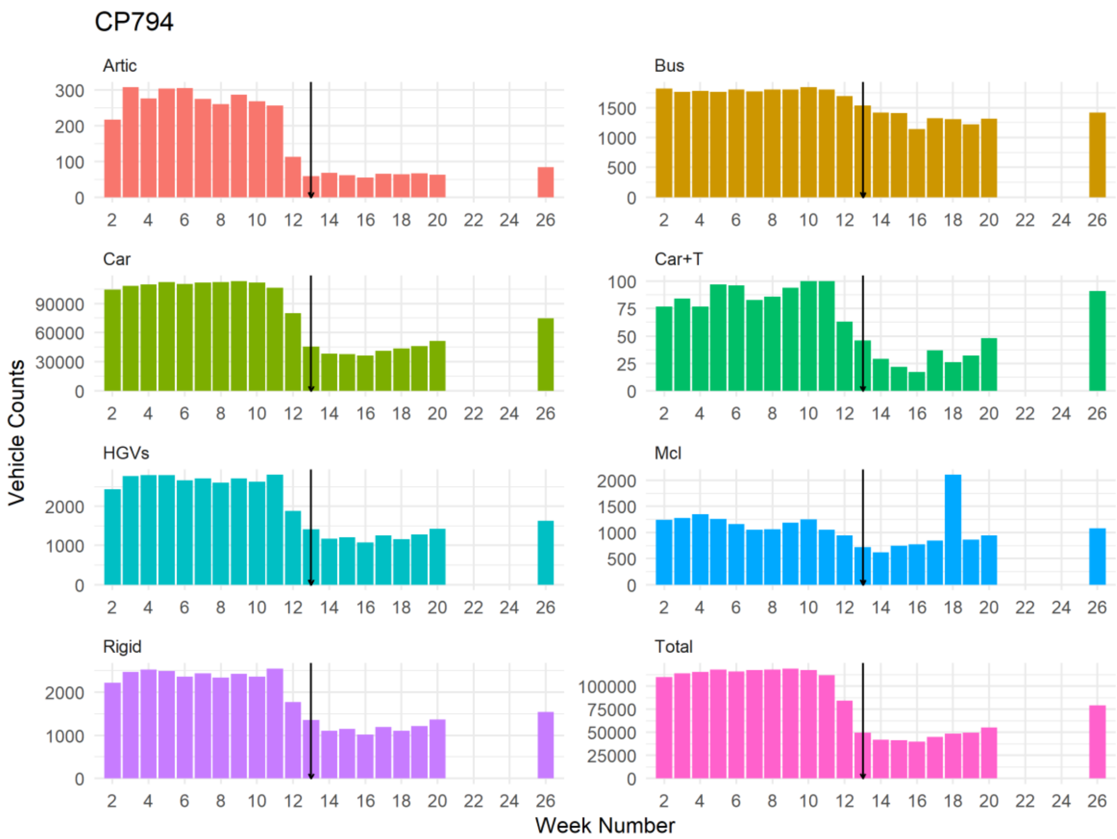
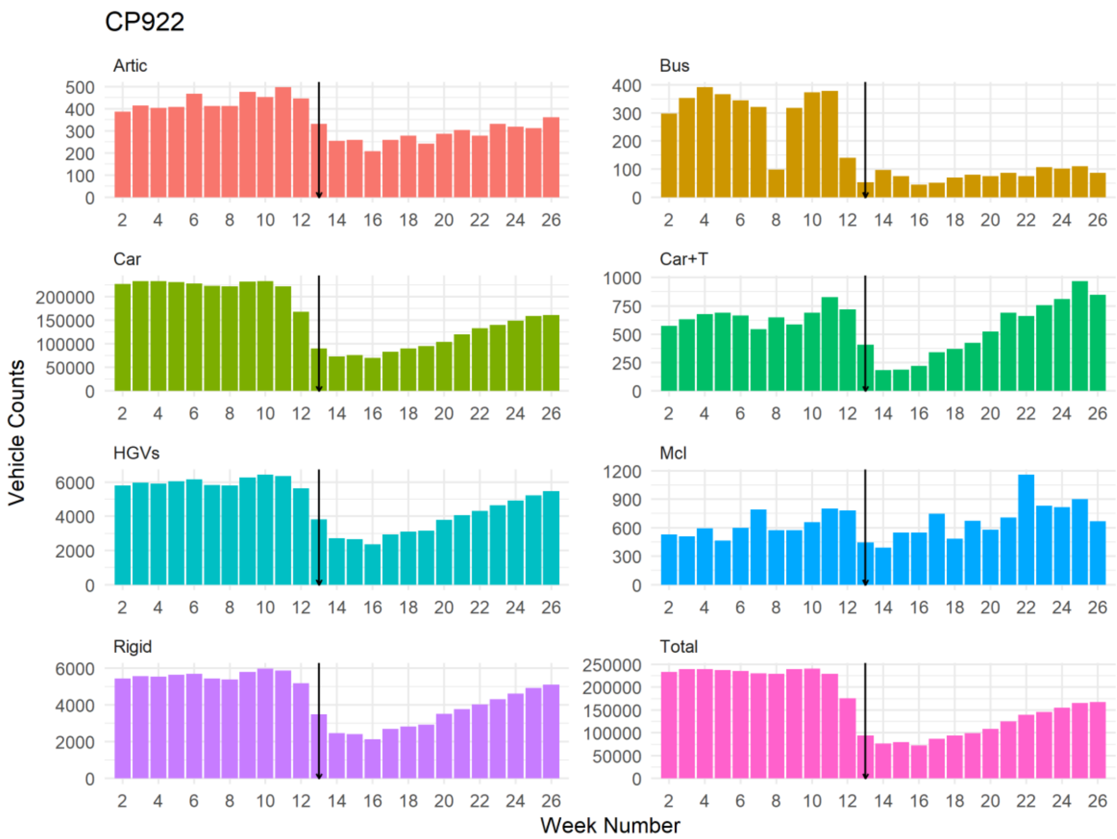


Figure 3-22 Weekly Traffic Numbers by Vehicle Type, Count Point 910 (A2 Bangor Road, Cultra)

Figure 3-23 Weekly Traffic Numbers by Vehicle Type, Count Point 922 (A55, Castlereagh)



The typical pattern at all 14 sites is a sharp decrease in total traffic from the start of week 10 (week beginning Mon 2nd Mar), reaching a minimum typically around week 14 (w.b. Mon 30th Mar). In most cases total traffic begins to steadily increase from around week 16 (w.b. Mon 13th Apr). This reflects the pattern for cars: patterns for other individual vehicle types, for example articulated HGVs, vary more from road to road, as might be expected. Also notable is an increase in the use of motorcycles. This may have been prompted by the need for social distancing: motorcycle owners may have used them more, as an alternative to public transport or car sharing.

As highlighted in section 3.1.2, road traffic is estimated to account for just under 30% of Northern Ireland's total NO_X emissions. Therefore, the decrease in traffic count of around two thirds observed just after the start of lockdown might be predicted to temporarily reduce Northern Ireland's total NO_X emissions by around 20%. However, measured ambient concentrations would not necessarily be expected to reduce by the same amount: this would depend on the importance of traffic emissions relative to other sources, at each monitoring site. It is predicted that short-term reductions in ambient NO_X concentrations observed at roadside sites are likely to be greater than 20%.

3.2.4 Non-Road Transport

3.2.4.1 Air

The impact of the Covid-19 lockdown measures on the air transport industry have been well publicised in the media. Figure 3-24 shows weekly flights to and from Belfast City Airport from January 2018 to May 2020. The graph shows the typical seasonal variation through 2018 and 2019, with flight numbers higher in the summer holiday season, lower in the winter. The effect of Christmas is also visible, as well as a dip around week beginning 25th Feb 2018, due to a period of severe weather which resulted in many flight cancellations. The graph clearly shows the sharp drop in flights, beginning in this case from the beginning of March 2020 (i.e. before the lockdown began).

Figure 3-24 Weekly Flights, Belfast City Airport Jan 2018 - May 2020

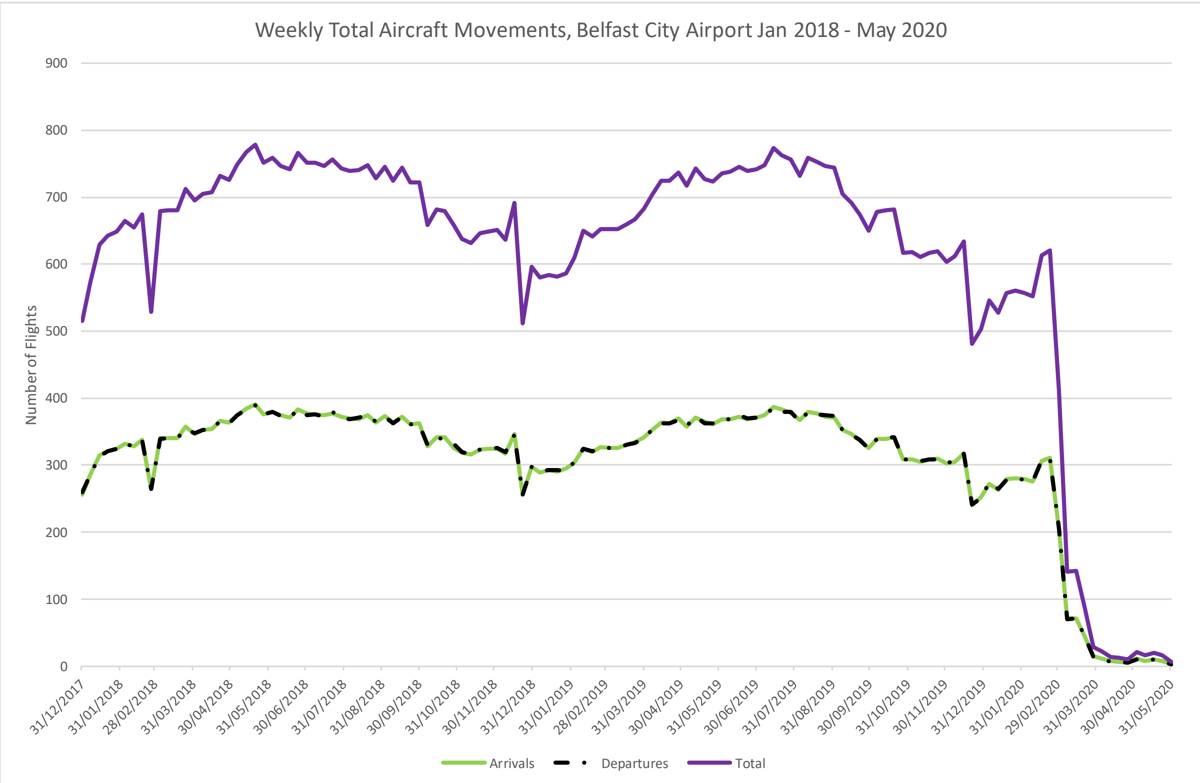
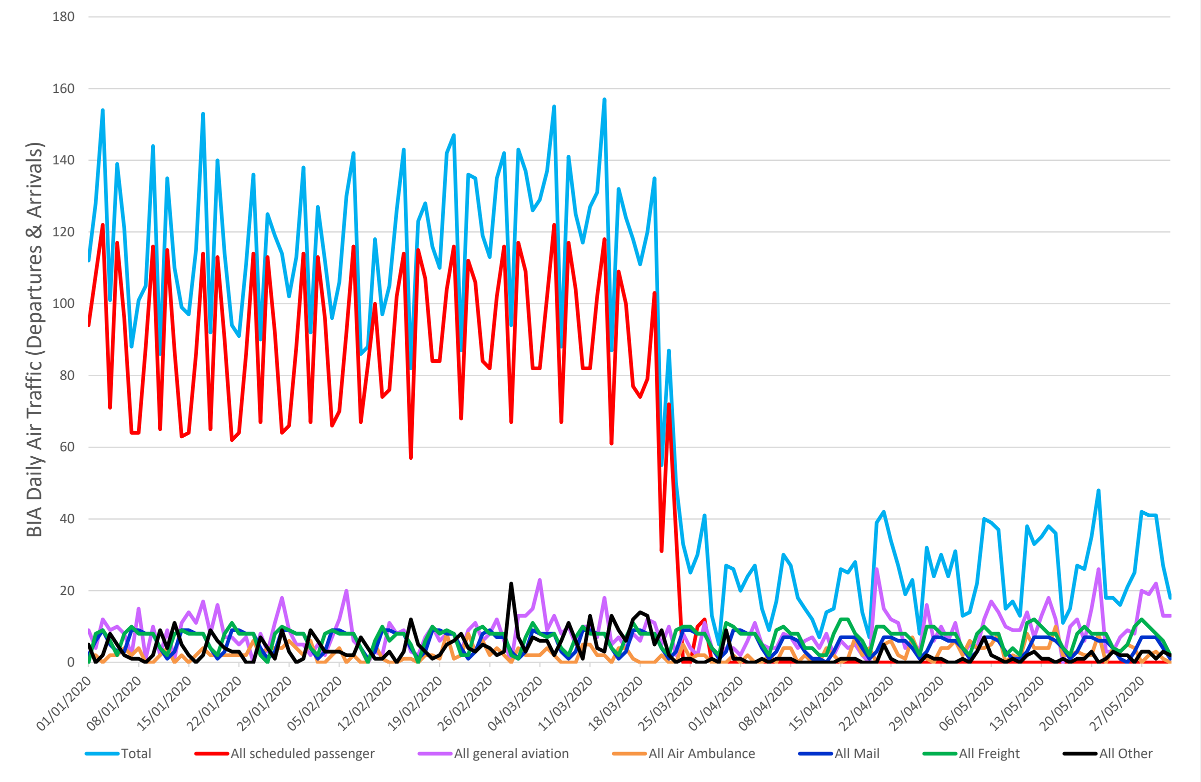


Figure 3-25 shows daily aircraft traffic into and out of the larger Belfast International Airport (BIA), from 1st Jan 2020 to 31st May 2020. Before lockdown, scheduled passenger flights made up the majority of aircraft movements and these decreased dramatically when the restrictions were imposed.

The small proportion of other types of flights, providing essential services such as air ambulance, mail and freight, were relatively unaffected. It is notable that the steep drop in flights did not begin until mid-March at this airport, compared to at the beginning of March at Belfast City Airport (BCA).

Figure 3-25 Daily Air Traffic, Belfast International Airport, 1st Jan - 31st May 2020



To help estimate the likely impact on air pollutant emissions, we estimate the reduction in flight numbers as follows:

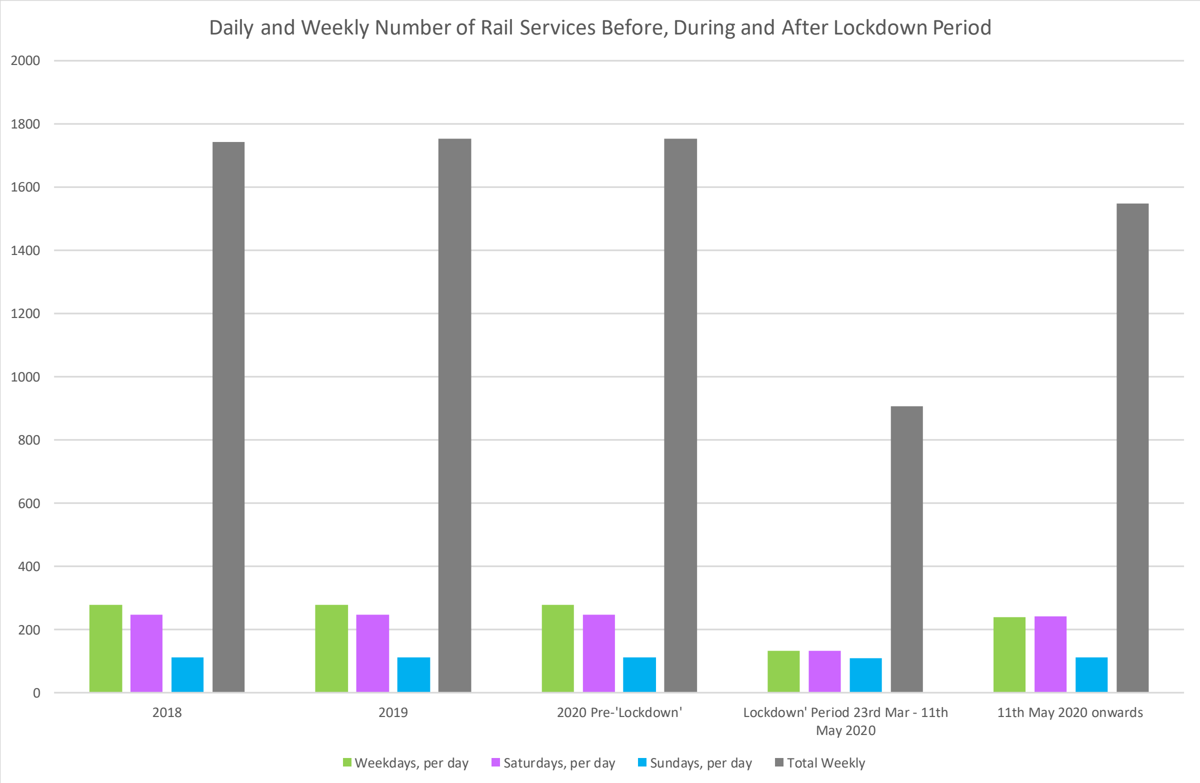
- BCA – in the 13 weeks beginning 1st Mar – 24th May 2020 the total number of aircraft movements was 942 compared with 9,114 in the equivalent 13-week period in 2019 and 9,363 in the equivalent 13-week period in 2018. This equates to just 10% of the usual traffic, over this three-month period.
- BIA – in the period 1st Mar – 31st May 2020 the total number of aircraft movements was 4,434 compared with 11,051 in the same period in 2019 and 10,047 in the same period in 2018. This equates to 42% of the usual traffic over this three-month period. Belfast International Airport may have been less affected if it deals with more essential services such as freight.
- For both airports together, the total aircraft movements over the period March to May 2020 period appear to have been reduced to 27% of the usual numbers.

The reduction in air traffic is expected to also have reduced road traffic to and from the airports. This may be reflected in the traffic count data, for example on the A2 near Belfast City Airport.

3.2.4.2 Rail

According to information provided by Translink rail services in Northern Ireland went to a ‘Sunday +’ timetable at the beginning of the lockdown period on 23rd Mar 2020. This reduced total weekly services from 1754 to 908, just 52% of the normal number of services. The service was increased to a ‘Saturday +’ timetable of 1548 services per week, as of 11th May. This is 88% of the normal number of services. The reduction in rail services is illustrated in Figure 3-26.

Figure 3-26 Rail Services Before, During and After Covid-19 Lockdown Period



3.2.4.3 Shipping

No data on the impacts of the Covid-19 restrictions on shipping to and from Northern Ireland are currently available in the public domain. However, it is reasonable to assume that passenger ferry sailings (into and out of Belfast and Larne) have substantially fallen during the lockdown period. As an estimate it may be reasonable to assume a decrease of similar magnitude to that recorded for air travel, perhaps 70-75%, in passenger shipping.

Freight shipping is estimated to have been affected to a lesser extent, as the shipping of food and other essential goods into Northern Ireland will have continued.

This will also have reduced traffic on the roads serving the ports.

3.2.5 Industrial Activity

The Northern Ireland Environment Agency (NIEA) regulates 'Part A' industrial installations in Northern Ireland, including:

- Power generation
- Waste to Energy plant
- Cement processes
- Glass manufacturing processes
- Non-ferrous metal processes.

Information provided by NIEA's Industrial and Radiochemical Inspectorate (IPRI) to DAERA stated the following

1. IPRI was not aware of any increases in emissions from any of the above sectors as a result of the Covid-19 pandemic.
2. Emissions from the cement, glass and non-ferrous metal sectors had been lower than usual during the six-week period from mid-March to the end of May, as some plant had been shut down. At the time of the communication in early June, IPRI reported that most had re-started, though at reduced capacity.

3. None of Northern Ireland's three power generating plant had notified NIEA of any breaches of their emission limits.

The lockdown therefore appears to have reduced emissions from NIEA-regulated industrial processes.

3.2.6 Agriculture

NIEA also regulates the FDM (Food Drink and Milk) and SA (Slaughtering and Animal By-product) sectors. These are the largest group of industrial installations regulated by IPRI. Information was provided by NIEA to DAERA on the effects of the lockdown.

The production of meat and poultry products is largely dictated by the life cycle of the animals involved, as well as to some extent the chilling capacity of the abattoirs. There is therefore limited capacity to speed up or slow down these processes. NIEA were therefore unaware of any significant increase or decrease in emissions from the agriculture sector.

They did however note that some processes had "*issues with outbreaks of Covid-19 amongst their staff because of working/living arrangements*"; outbreaks at meat processing plant were later reported in the national news, not specific to Northern Ireland but in various parts of the UK.

Emissions associated with the rearing and keeping of farm animals or poultry for meat, dairy or eggs, and the management of their waste products, are also largely dependent on the life cycles of the animals. We therefore assume these not to have been greatly affected by the lockdown. Similarly, emissions associated with the growing and harvesting of crops, for example application of fertilizers, we would assume to have been relatively unaffected.

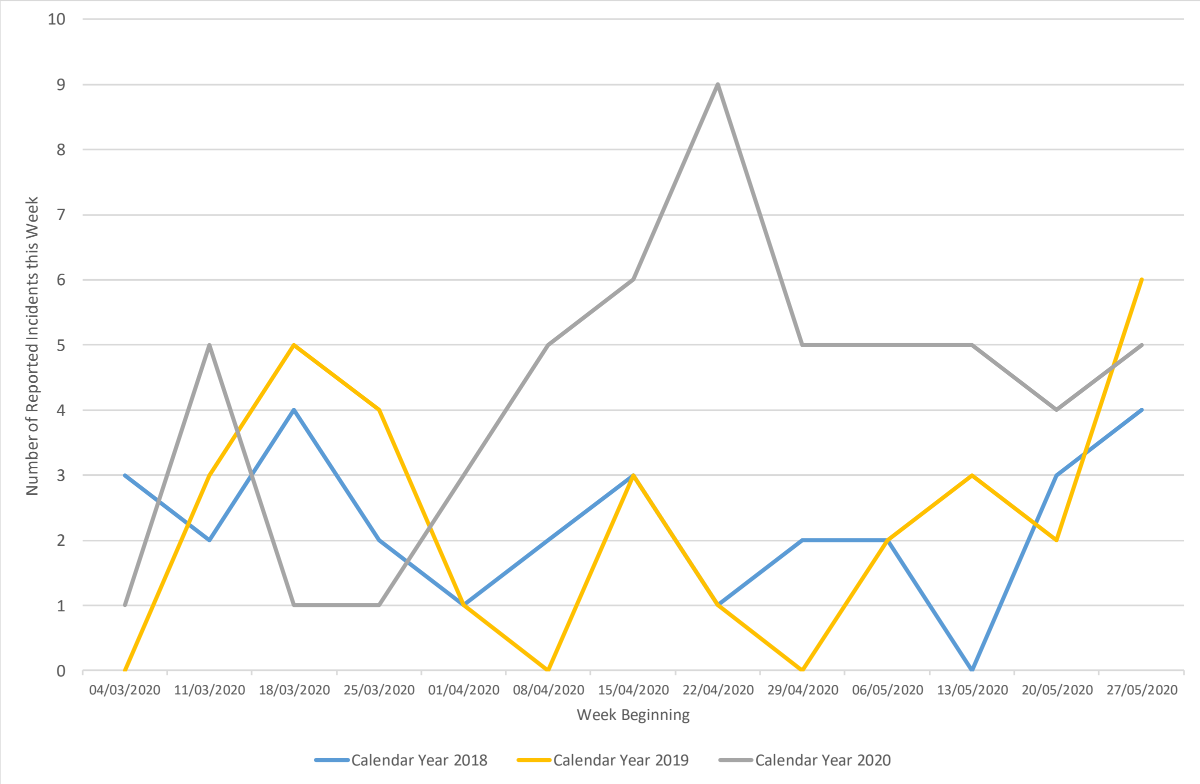
3.2.7 Waste Burning: Non-Domestic

NIEA investigates reported incidents of waste crime, which include fly-tipping and unauthorised waste burning. NIEA has investigated the incidence of waste crime during the period 16th March to 3rd June 2020, to identify whether the Covid-19 lockdown restrictions resulted in any new trends.

NIEA received 284 waste incident reports during this period, compared with 212 in the same period in 2019 and 244 in the same period in 2018 (Northern Ireland Environment Agency, 2020). They reported that the increase was driven by a rise in reports of small-scale fly-tipping. However, there were 49 reported waste burning incidents, and NIEA noted an "*increase in burning of waste in both residential and commercial settings*". There were however, no 'hotspot' locations evident.

Figure 3-27 below illustrates the weekly number of waste burning reports recorded by NIEA over the period March to May 2020. There is evidence of an increase in 2020, compared to the same period in 2019 and 2018, during April and into May.

Figure 3-27 Weekly Reports to NIEA of Waste Burning, March-May 2020 Compared with 2018 and 2019



3.2.8 Waste Burning: Domestic

Northern Ireland's District Councils keep records of complaints about smoke, odour and other nuisance caused by domestic burning. This includes outdoor burning such as bonfires and barbecues, as well as smoke from chimneys and appliances. Information provided by each District Council, via DAERA, is summarised below.

- Antrim and Newtownabbey Borough Council reported the following: during 1st Jan – 24th Jun 2020, there were 29 complaints about smoke from burning 'within the curtilage' (i.e. within the boundary) of a property (e.g. in gardens), compared to eight in the first six months of 2019 and 12 in the first six months of 2018. They reported eight complaints regarding smoke from burning within the property itself (e.g. from a chimney), during 1st Jan – 24th Jun 2020 compared to six in the first half of 2019 and seven in the first half of 2018.
- Armagh, Banbridge & Craigavon reported eight complaints about domestic bonfires in months January to June 2020 compared to 12 in the whole of 2019. Complaints about commercial bonfires totalled 74 in the first half of 2020 compared to 96 in the whole of 2019 and 112 in the whole of 2018. The Council considered this a small increase compared to expected levels.
- Belfast City Council reported complaints on 'Smoke from domestic chimney in smoke control zone': there were 22 such complaints in the first half of 2020 compared to 79 in 2019 and 33 in 2018. So in this case, there were fewer such complaints in 2020 so far, than in the corresponding period in recent years. Belfast CC also reported smoke complaints from 'domestic bonfires': there were 27 in Jan-Jun 2020 compared to 20 in Jan-Jun 2019 and 36 in Jan-Jun 2018.
- Causeway Coast and Glens reported 20 domestic smoke complaints in Jan-Jun 2020, all but two of these relating to outdoor burning. There were 14 such complaints in Jan-Jun 2019 (all outdoor) and 15 such complaints in Jan-Jun 2018 (all outdoor apart from three which related to a defective chimney.)
- Derry and Strabane District Council reported 12 complaints relating to burning 'within the curtilage of a domestic property', and two relating to burning within a property, during January

to June 2020. This compared to a total of 12 such complaints in Jan-Jun 2019 and 16 such complaints in Jan-Jun 2018.

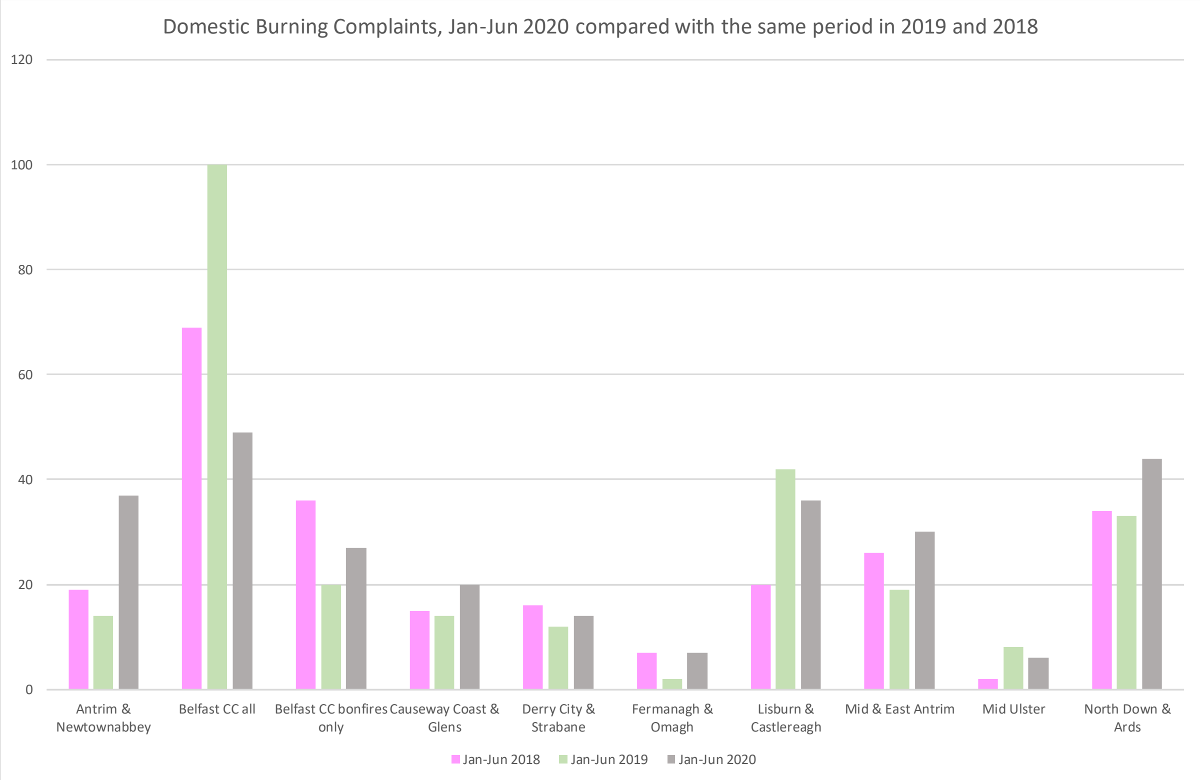
- Fermanagh and Omagh reported seven complaints in Jan-Jun 2020; more than in 2019 but the same as in 2018.
- Lisburn & Castlereagh reported 36 domestic smoke complaints (mostly outdoor) in Jan-Jun 2020. This compared with 42 in Jan-Jun 2019 and 20 in Jan-Jun 2018.
- Mid and East Antrim reported 30 domestic burning complaints in Jan-Jun 2020 compared to 19 in Jan-Jun 2019 and 26 in Jan-Jun 2018.
- Mid Ulster District Council reported a total of six domestic burning complaints in weeks 1-25 of 2020 compared to eight in the same part of 2019 and two in the same part of 2018.
- Newry, Mourne and Down reported a total of 29 domestic burning complaints in the period 1st January to 21st July 2020, compared to 26 complaints in the whole of 2019, and 20 in the whole of 2018. The majority of these were 'within the curtilage' of the properties concerned.
- North Down and Ards Borough Council reported 40 complaints about smoke from waste burning plus four of smoke from flues in the period 1st Jan – 24th Jun 2020, compared to 25 of waste burning and eight of smoke from flues in the first half of 2019, and 26 of waste burning and eight of smoke from flues in the first half of 2018.

Figure 3-28 illustrates the reported incidences as a bar chart. There was some variation in the type of information provided by the District Councils, and the type of incidents counted. This made it difficult to reliably compare Councils one with another, so this chart is only intended to show how each individual Council's figures have changed over the years. Neither Armagh, Banbridge and Craigavon or Newry, Mourne and Down have been included in the chart, as both of these councils only provided 2018 and 2019 figures for the whole year, not the first six months. Their data are therefore not comparable 'like for like' with those of the other districts.

The majority of the complaints related to outdoor burning, particularly of waste or rubbish, rather than smoke from chimneys or appliances.

Some Districts reported clear evidence of increased incidence of nuisance complaints relating to domestic burning, compared to the same period in previous years. (These were: Antrim and Newtownabbey; Armagh Banbridge and Craigavon; Causeway Coast and Glens; Mid and East Antrim; Newry, Mourne and Down, and North Down and Ards.) However, this was not the case in others, for example Belfast City Council, Derry City and Strabane, and Lisburn and Castlereagh.

Figure 3-28 Domestic Burning Complaints, Jan-Jun 2020 compared with the same period in 2019 and 2018 (where the data were supplied in a way that could be compared.)



The data therefore indicate that in some (but not all) areas of Northern Ireland, there may have been localised, short-term nuisance effects and impacts on air quality, due to the outdoor burning of waste on domestic premises. This may have resulted from interruptions to normal routes for disposal of waste – for instance interruption to garden waste collection services, or closure of local recycling centres.

3.2.9 Accidental Fire in Belfast Docks Area, 24th May

On the evening of 24th May it was reported that a large fire had broken out at the factory of the Bombardier aerospace company, on Airport Road, in the docks area of Belfast. Online news reports showed a large plume of dark smoke rising into the air (https://www.bbc.co.uk/news/uk-northern-ireland-52793539 , https://www.newsletter.co.uk/business/huge-fire-blazes-bombardier-aerospace-plant-50-firefighters-scene-2863646).

Despite the size of the fire, no increase in PM_{10} concentrations was evident in the data from the two sites in Belfast which measure this pollutant, or North Down Holywood A2. Modelled wind direction data for Belfast Centre (available from UK-AIR) show that the wind direction during the period 24th – 26th May was predominantly from the west. This would have meant the smoke from the fire was blown out to sea, rather than inland over the city.

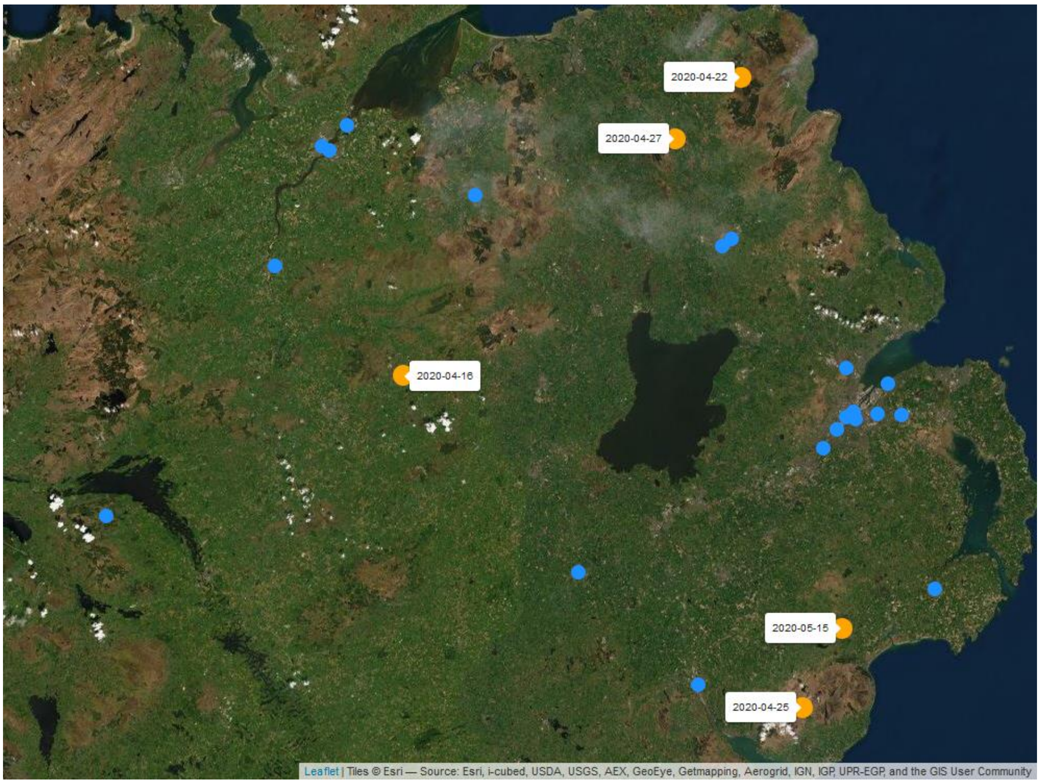
3.2.10 Wildfires

In addition to causing damage to habitats, wildfires can result in an increase in pollutants released into the atmosphere. A number of wildfires occurred in April and May in Northern Ireland, in or near Areas of Special Scientific Interest (ASSI). The dates and locations of the fires are shown in Table 3-4 and Figure 3-29.

Table 3-4 Information of wildfires near ASSI, Apr – May 2020 (Information provided by DAERA)

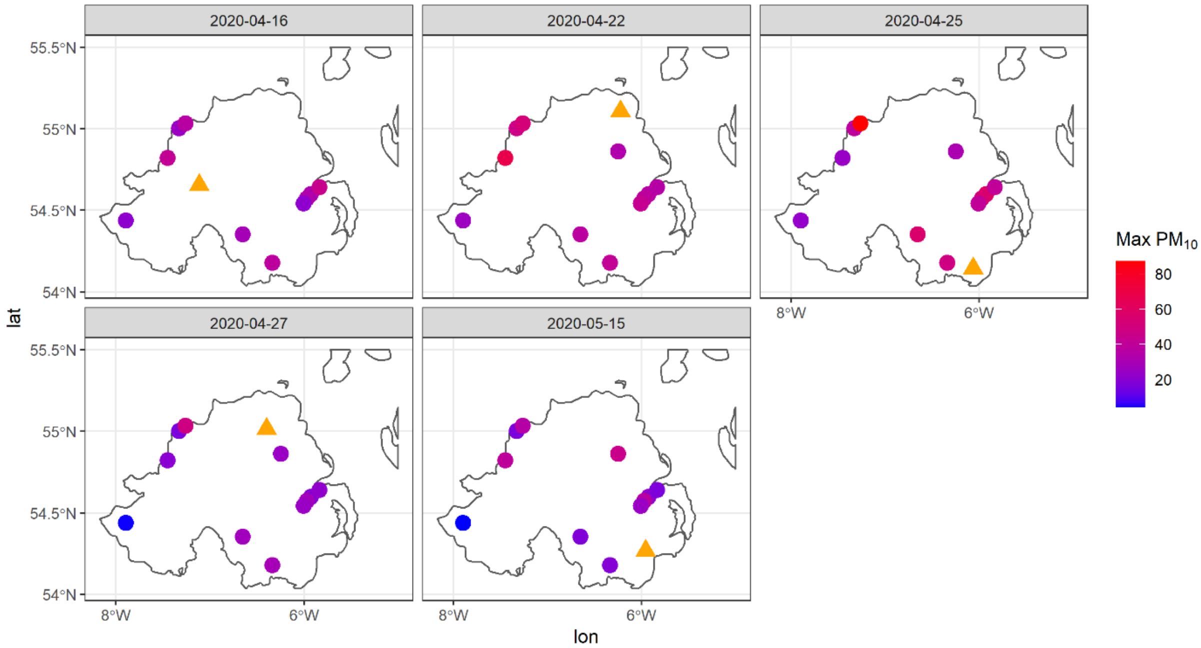
Date	Location
16th April	Murrins ASSI (150ha burnt)
22nd April	Altarichard, ASSI, SAC (340ha burnt)
25th April	Eastern Mournes ASSI and SAC (600ha burnt)
27th April	Dunloy Bog ASSI
15th & 16th May	Wildfire at Castlewellan Forest

Figure 3-29 Location of wildfires near ASSIs (estimated location) shown as orange points. Blue points represent the location of the Northern Ireland's Air Quality Monitoring Sites



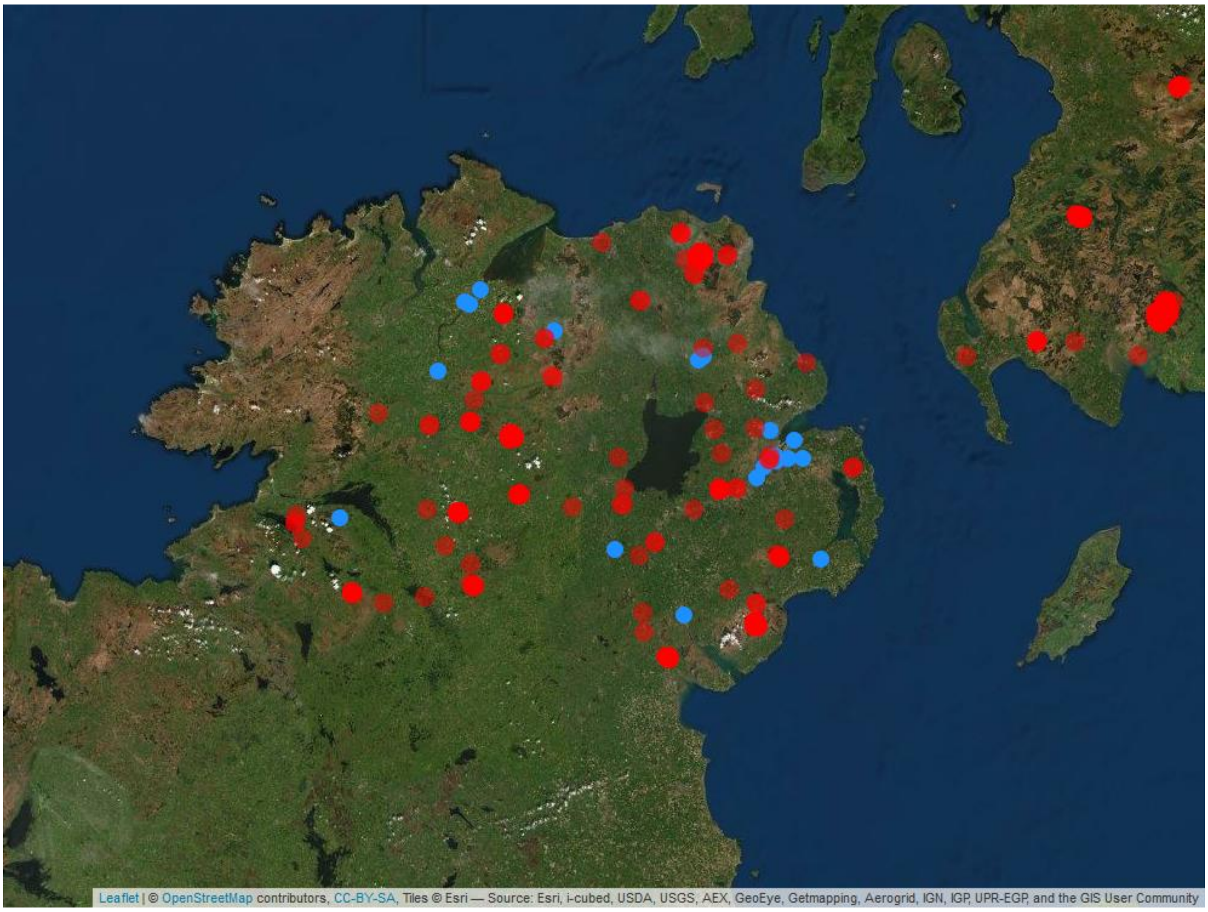
To investigate the impact of the fires on local air quality, the maximum hourly PM_{10} levels on the day of each recorded fire are shown in Figure 3-30. The maps do not show any large increase in PM_{10} at monitoring sites near to the fire, and when the time series data was investigated, there were no obvious spikes in PM_{10} levels that could be attributed to the fires.

Figure 3-30 Max hourly PM_{10} at each site (where PM is measured) on the date of the recorded fires.



Additional potential fires were investigated using satellite data. The Fire Information for Resource Management System (FIRMS) provides information on fire locations and hotspots from satellite instruments (MODIS and VIIRS). Datasets for January to May 2020 have been downloaded for the VIIRS active fire hotspot locations. VIIRS has two products - from the Suomi NPP and the NOAA-20 satellites. A combined data set with the VIIRS active fire products is shown in Figure 3-31 – the data shows detected hotspots which is an indication of where fires may have occurred, as red dots. Blue dots are the locations of the air quality monitoring sites.

Figure 3-31 Hotspots from VIIRS 375m data from Suomi-NPP and VIIRS 375m NRT (NOAA-20)



We acknowledge the use of data and/or imagery from NASA's Fire Information for Resource Management System (FIRMS) (https://earthdata.nasa.gov/firms), part of NASA's Earth Observing System Data and Information System (EOSDIS). (https://earthdata.nasa.gov/earth-observation-data/near-real-time/citation#ed-lance-disclaimer)

Figure 3-32 below shows the locations of hotspots detected from Suomi-NPP and NOAA-20 for each day that at least one hotspot was detected, from January to May 2020. Also shown are the maximum hourly PM_{10} levels measured on that date, from the monitoring stations. Hotspots from Suomi-NPP and NOAA-20 are shown as orange triangles. The maximum PM_{10} hourly concentration at each monitoring station that measured PM_{10} is given by the colour in the legend.

PM_{10} measured at monitoring sites close to the hotspot locations, does not appear to be elevated when compared to other sites. This may be due to local meteorological conditions, resulting in the smoke plume being directed away from the area, or at high altitudes.

On 29th May, 'spikes' in PM_{10} were measured, of 308 µg m^{-3} at Belfast Stockman's Lane (09:00) and 181 µg m^{-3} at Armagh Lonsdale Road (08:00). VIIRS detected a hotspot in the vicinity of Belfast on this date, so it is possible that the Belfast Stockman's Lane spike was due to a local fire. However, PM_{10} at nearby Belfast Centre was not elevated. Armagh Lonsdale Road is unlikely to have been affected by a fire in Belfast, due to the distance. Figure 3-33 shows time series of hourly PM_{10} from four monitoring stations between 27th – 31st May 2020 (left), and maximum PM_{10} hourly concentration at each monitoring station on 29th May (right).

Figure 3-32 Hotspots from Suomi-NPP and NOAA-20 (shown as orange triangles). Maximum hourly mean PM_{10} hourly concentration at each monitoring station given by the colour in the legend.

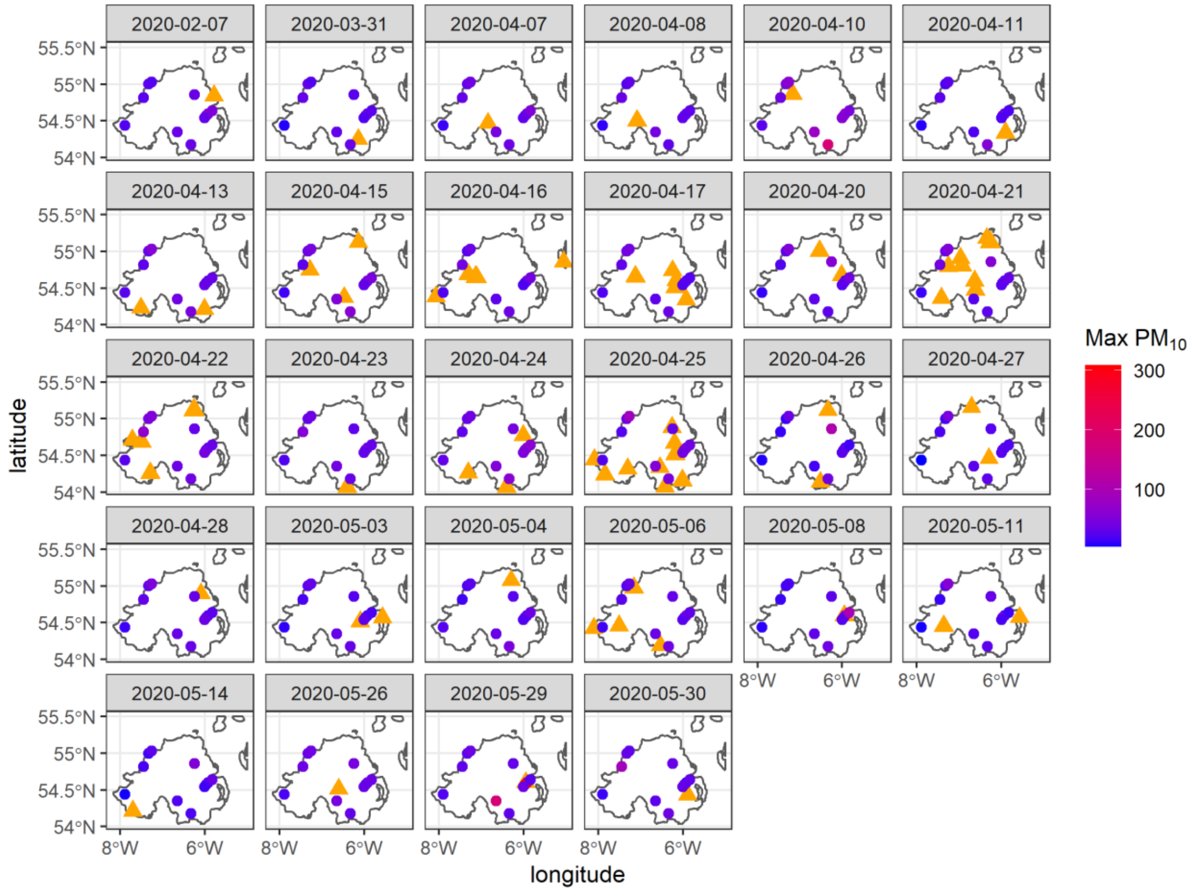
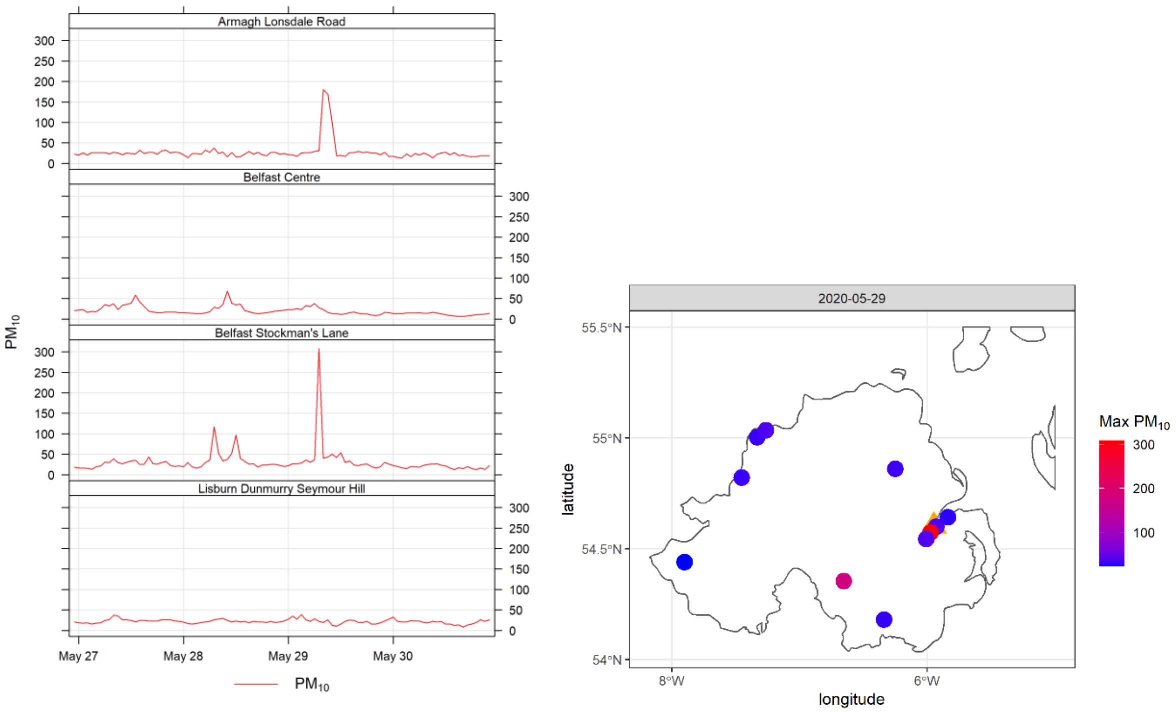


Figure 3-33 Left: Time series of hourly PM_{10} from four monitoring stations between 27-31st May 2020. Right: Maximum PM_{10} hourly concentration at each monitoring station on 29th May.



4 Review of Meteorology and Air Mass Back Trajectories

4.1 Meteorology

Meteorology can have a large impact on levels of pollutants in the atmosphere. Ozone, for example is formed via chemical reactions between NO_X and VOCs, in the presence of sunlight. Therefore, hot, stable, sunny days can result in enhanced ozone formation. Variations in wind speed and direction can also influence pollutant levels, through accumulation, dispersion or long-range transport. As a result, it is important to assess meteorological variations when investigating changes in pollutant concentrations.

Figure 4-1 shows wind roses for Belfast City Airport for each month from January to May 2020. For the first two months of the year there were strong south-westerly winds. Storm Ciara and Storm Dennis, during February, brought very strong winds and heavy rain to Northern Ireland (and across most of the UK). Average wind speeds in February, at Belfast Airport, were 6.8 ms^{-1}. By March the mean wind speed had dropped and through April North Easterly winds were prevalent. May was generally calm and sunny.

Figure 4-1 Monthly wind roses for Belfast City Airport from January to May 2020. Data source: NOAA Integrated Surface Database (ISD)(2016) https://www.ncdc.noaa.gov/isd

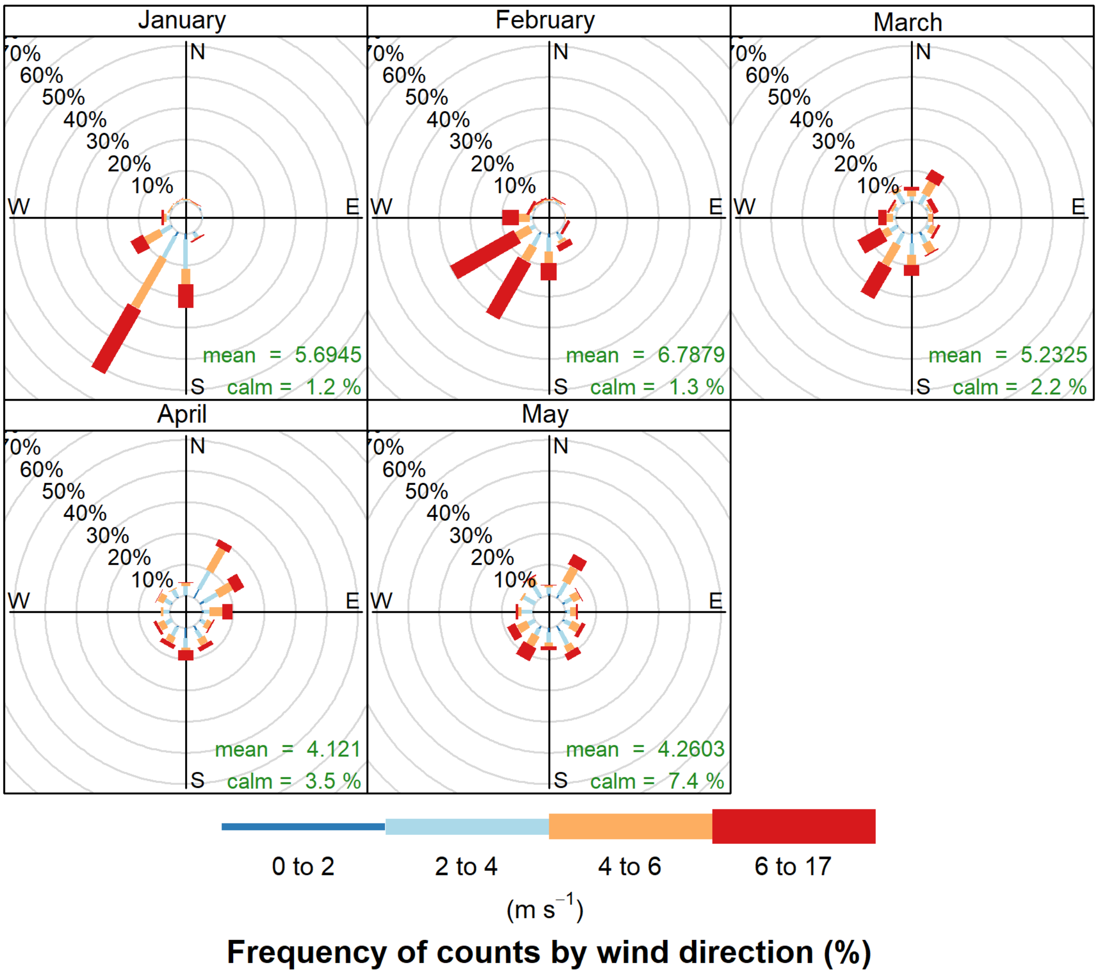
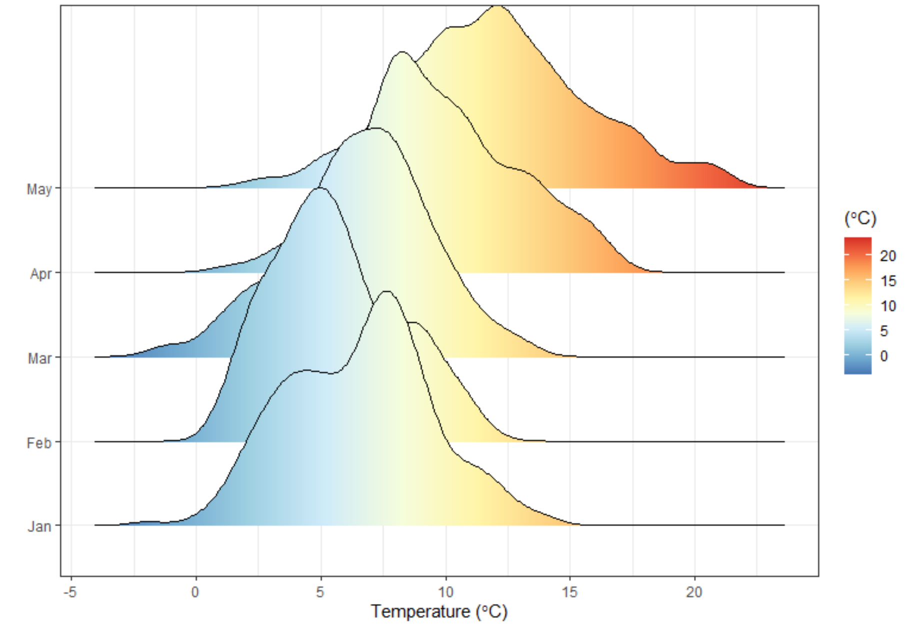


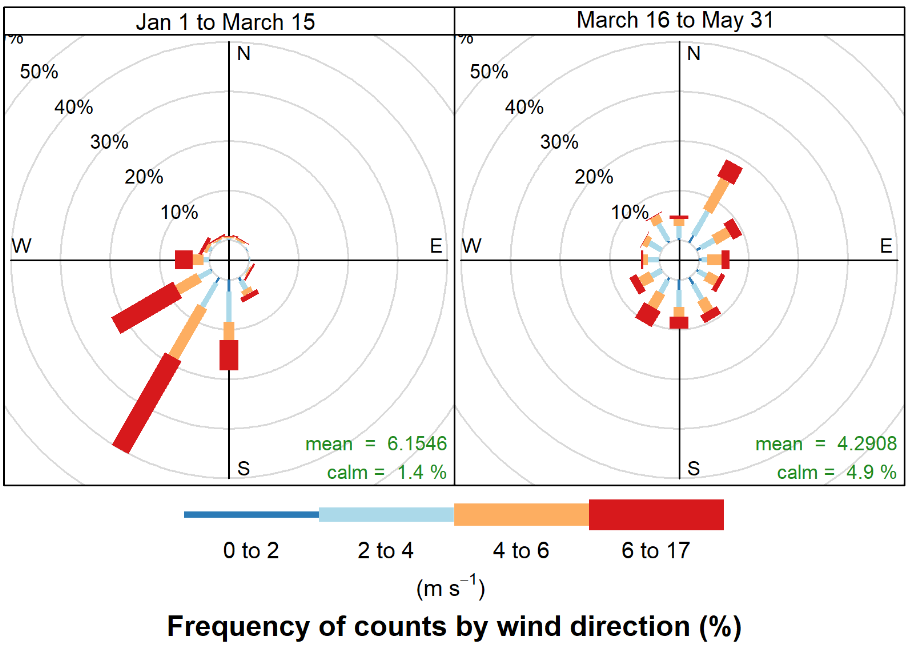
Figure 4-2 shows a frequency density plot of hourly mean ambient temperature as measured at Belfast City Airport in January to May 2020. This illustrates how temperatures changed through the first five months of 2020.

Figure 4-2 Frequency density plot of ambient temperature, measured at Belfast City Airport from January to May 2020 Data source: NOAA Integrated Surface Database (ISD)(2016) https://www.ncdc.noaa.gov/isd



Social distancing was implemented on 16th March. Figure 4-3 compares the wind speeds and directions in the period before social distancing (1st Jan – 15th Mar), and the subsequent period to the end of May. Before 16th March the wind direction was predominately from the south-west with a mean wind speed of 6.2 ms^{-1}. From March 16th to May 31st the mean wind speed had dropped to 4.3 ms^{-1} and the wind direction was more variable. These seasonal variations in meteorology may have influenced Northern Ireland's air quality during the relevant periods.

Figure 4-3 Wind roses for Belfast City Airport split into two periods - prior to and after social distancing was implemented on March 16th.

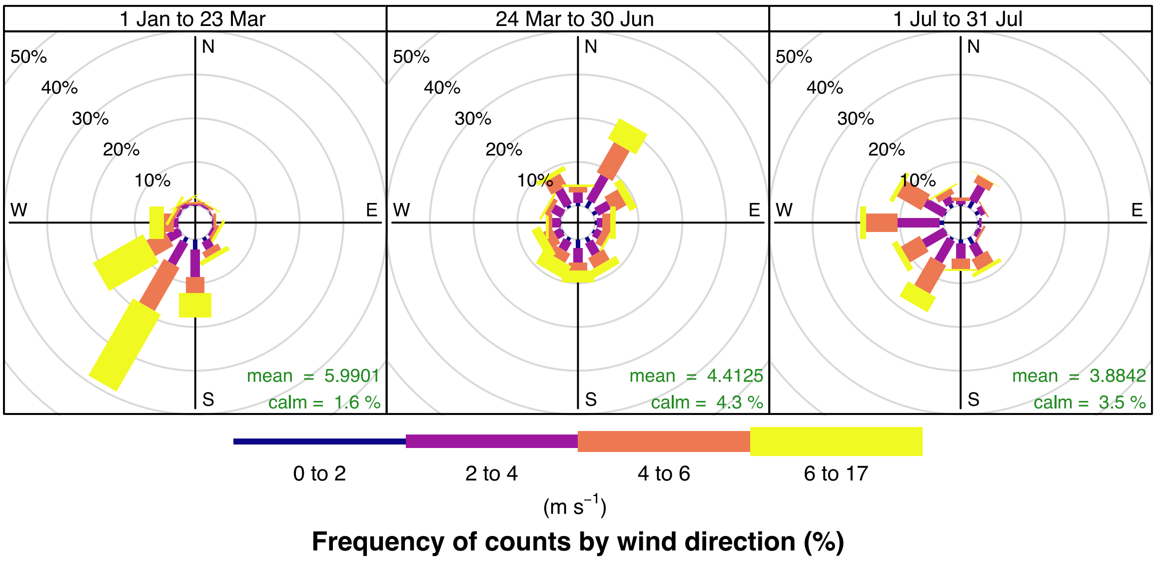


4.2 Wind and Air Mass Back Trajectory Analysis

For pollutants such as PM_{10}, $PM_{2.5}$ and O_3 there can be significant contributions from non-local sources. In the case of PM, regional contributions from sources outside Northern Ireland can dominate total concentrations under some conditions. This is especially true during springtime when nitrogen-based fertilizers are applied across Europe, which results in the formation of ammonium nitrate particulate that contributes to both PM_{10} and $PM_{2.5}$.

One of the striking aspects of 2020 weather has been the difference in meteorology before and during the lockdown period. Before lockdown began on 23rd March, the year was dominated by strong westerly winds, as seen in Figure 4-4, which will typically have brought relatively clean air to Northern Ireland. Over this period the mean wind speed was 6.0 ms^{-1}. After lockdown began, the wind speed was lower, with a mix of wind directions including some north easterly winds. For the period 23rd March to 30th Jun, the mean wind speed was 4.4 ms^{-1} i.e. considerably lower than the pre-lockdown period. Going into July, wind speeds were slightly lower (mean 3.9 ms^{-1}) but there was a return to more westerly and south-westerly wind directions.

Figure 4-4 Wind rose for Belfast City Airport for 1st January 2020 to 31st July 2020, before, during and after main lockdown period.2020.

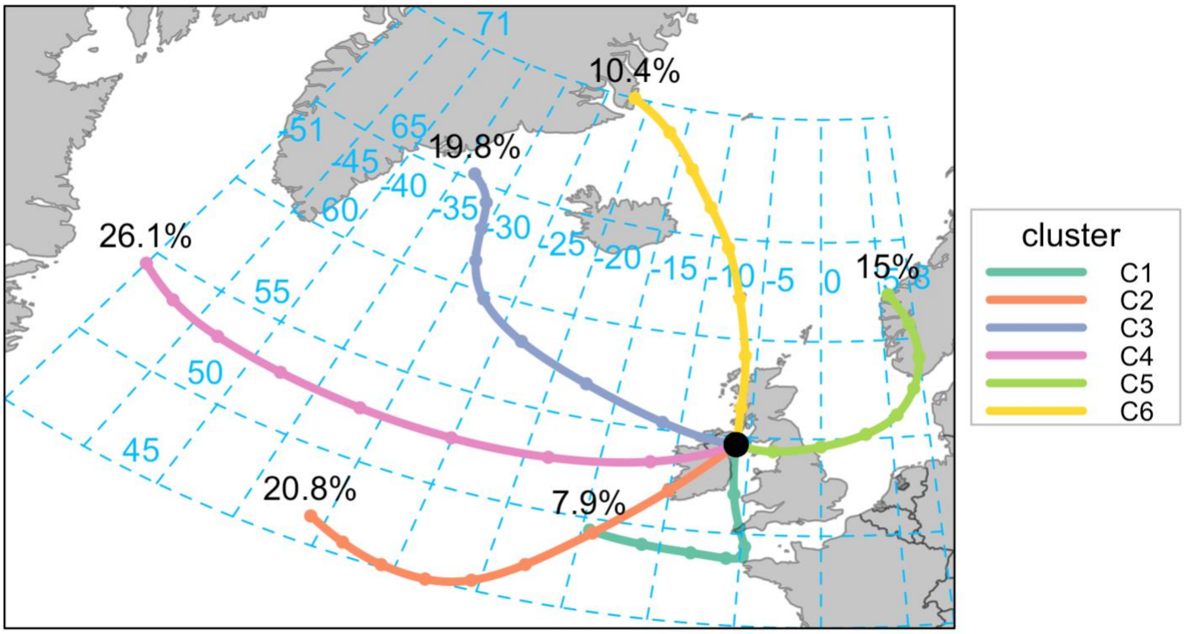


Such changes in meteorology will strongly influence the concentrations of different pollutants. For locally produced emissions (e.g. at a city scale), the lower wind speeds during the lockdown period would tend to result in higher concentrations of most pollutants, certainly for emissions from road vehicles and domestic combustion. This characteristic of meteorology during 2020 clearly will have an influence on the analysis of a 'Covid-19 effect' – which is the reason why sophisticated statistical models are required to determine changes in concentrations without the confounding effect of the weather.

As mentioned previously, the origin of air masses can also have an important effect on the concentrations of many pollutants and especially PM. To understand the effects of how air mass origins affected concentrations of PM, 96-hour back trajectories have been run, based on the location of the Belfast Centre monitoring site. These trajectories provide the estimated location of an air mass arriving at the monitoring site, for up to 96 hours, run every 3 hours since the start of 2020 using the Openair R package.

To further understand the linkage between air mass origin and pollutant concentration, cluster analysis has been undertaken to group similar origin air masses, as shown in Figure 4-5.

Figure 4-5 Cluster analysis of air mass origins throughout 2020 from January to July. The numbers show the percent of time the air was from each cluster.

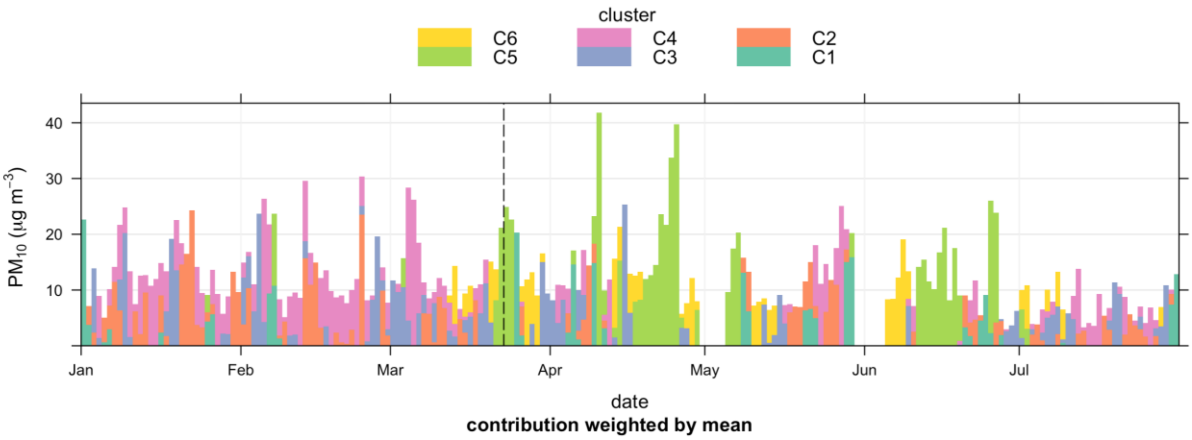


The clusters shown in Figure 4-5 can be linked with PM_{10} concentrations at the Belfast Centre site to explore the relationship between air mass origin and concentration; this is shown in Figure 4-6. Note that the colours are the same as those used in Figure 4-5. This plot shows very clearly that during the pre-lockdown period, meteorological conditions were such that air masses arriving at Belfast Centre tended to come from the Atlantic (represented by clusters C2, C3 and C4). These are likely to have brought relatively clean air to the site.

However, the onset of lockdown coincided with a change in weather conditions. During the lockdown period, particularly in April and early May, the air masses arriving at Belfast Centre were much more influenced by easterly (continental origin) winds, represented by cluster C5. These are likely to have brought more polluted air to the site.

There is evidence of this in Figure 4-6: the highest daily mean PM_{10} concentrations are seen in the lockdown period when the wind origin was from continental Europe (C5). On average, the PM_{10} concentration for cluster 5 was 19 μgm^{-3} whereas for the Atlantic clusters (2, 3, 4, 6) it was about 11 $\mu g\ m^{-3}$. Similarly, for $PM_{2.5}$ cluster 5 was associated with concentrations of 11 μgm^{-3} while the Atlantic clusters were associated with concentrations around 5-6 μgm^{-3}, which demonstrates the importance of air mass origin affecting concentrations of both PM_{10} and $PM_{2.5}$.

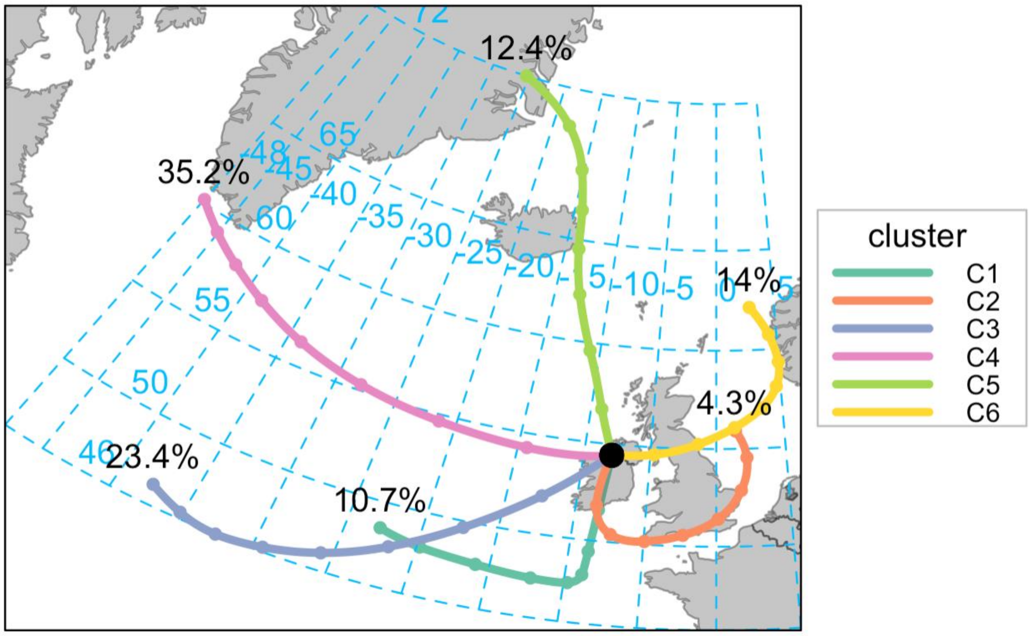
Figure 4-6 Daily mean PM_{10} concentration at Belfast Centre coloured by air mass origin. The vertical dashed line shows the lockdown date of 23rd March 2020.



What is clear from Figure 4-6 is that while there was significantly reduced activity in Northern Ireland and the rest of Europe (mostly resulting from reduced road transport emissions), the effect on PM_{10} (and $PM_{2.5}$) seems to have been small - however changes in meteorology could also have impacted this. These results suggest therefore that significant further ***international*** action would be required to reduce PM concentrations. Furthermore, the results highlight the importance of secondary PM, and thus support the view that reducing emissions of ammonia – an important precursor to secondary particulate pollution - may have a more important role in reducing PM. As previously highlighted in section 3.2.6, emissions of NH_3 in Northern Ireland were unlikely to have changed by much because agricultural activities mostly continued as normal. It is likely the same was true across Europe.

The situation for O_3 concentrations has some parallels with PM in that concentrations are dominated by regional and even global processes. The analysis in this section focuses on the rural site at Lough Navar that will not be strongly influenced by local emissions due to its rural background location. The clustered back trajectories for Lough Navar are shown in Figure 4-7.

Figure 4-7 Cluster analysis of air mass origins throughout 2020 from January to July centred on Lough Navar. The numbers show the percent of time the air was from each cluster.

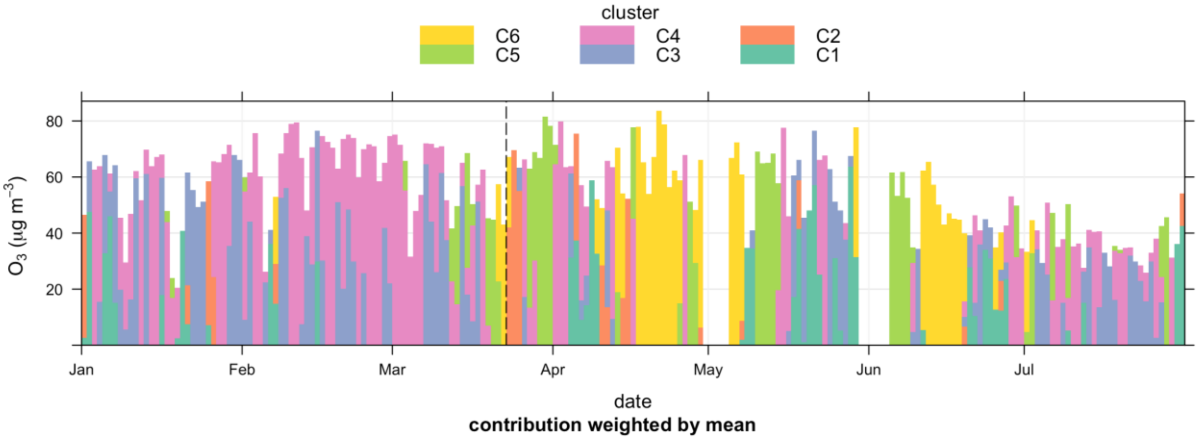


The O_3 trend by air mass origin is shown in Figure 4-8. This shows a similar pattern to Figure 4-6, in that before the start of lockdown, meteorological conditions were such that most of the air masses arriving at Lough Navar originated to the west, over the Atlantic (represented here by clusters C1, C3 and C4). Thus, pre-lockdown, Lough Navar was mostly receiving relatively unpolluted air masses.

However, after the onset of lockdown – particularly in April and early May – Lough Navar more frequently received air masses that had travelled or circulated over the UK or mainland Europe. These are represented here by clusters C2 and C6.

Despite the increased prevalence of continental-origin air masses, Figure 4-8 indicates that daily mean ozone concentrations were only slightly higher during lockdown compared with before. During July, wind directions again were predominantly westerly and daily mean ozone concentrations decreased.

Figure 4-8 Daily mean O_3 concentration at Lough Navar coloured by air mass origin. The vertical dashed line shows the lockdown date of 23rd March 2020.



The difficulty with the analysis of PM and O_3 is that it is not easy to determine a ‘Covid-19’ effect. Only regional scale air quality modelling is likely to provide estimates of any changes due to lockdown. However, the analyses do highlight that in terms of absolute concentrations of PM_{10}, $PM_{2.5}$ and O_3, the ‘lockdown’ period after 23rd March was associated with *elevated* concentrations of these pollutants in Northern Ireland. Moreover, these findings highlight the need to avoid the simplistic assumption that overall air quality must have improved, as a result of the observed reductions in local emissions.

5 Pollution Episodes

As highlighted in section 4 above, there were some significant episodes of elevated pollution during the lockdown period. This section looks at the periods with high pollution from January to May 2020.

5.1 Particulate Pollution Episodes

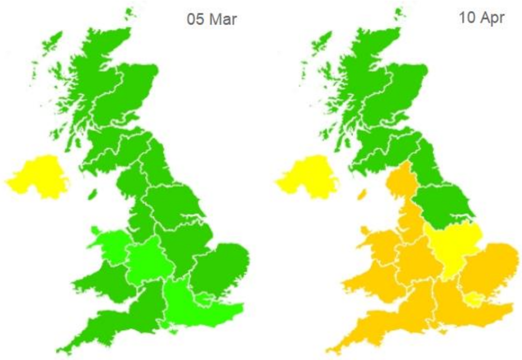
There were two days when PM_{10} reached the ‘Moderate’ band (as defined by the UK Air Quality Index) in Northern Ireland during this period.

- On 5th March 2020, before social distancing or lockdown began, Belfast Stockman’s Lane reported a 24-hour mean PM_{10} of 51 µg m^{-3}, putting the region into the ‘Moderate’ band by a small margin. The rest of the UK was in the ‘Low’ band, suggesting the PM_{10} at Belfast Stockman’s Lane had a local component.
- On 10th April 2020, ‘Moderate’ PM_{10} occurred at Newry Canal Street and Armagh Lonsdale Road. This was a wider pollution episode, with Wales and the majority of England also affected, as shown in the daily Air Quality Index (DAQI) map in Figure 5-1. An air pollution alert was issued on 9th April in relation to the forecast for 10th April. The Met Office attributed this episode to the predominantly settled, warm conditions, with light winds from mainland Europe. Such conditions commonly give rise to regional PM episodes of mostly secondary PM, formed from agricultural ammonia emissions in upwind countries.

Table 5-1 Days when PM_{10} was in 'Moderate' Band

Date	Monitoring Station	PM_{10} 24-hour mean (μgm^{-3})
05/03/2020	Belfast Stockman's Lane	51
10/04/2020	Newry Canal Street	52
	Armagh Lonsdale Road	54

Figure 5-1 Maps Showing DAQI for 5th March and 10th April 2020 (Source: UK-AIR)



The number of days in the period January to May 2020 when PM_{10} went into the 'Moderate' band or higher was less than in the same period in previous recent years: two days in Jan-May 2020, compared to nine in Jan-May 2019, five in Jan-May 2018 and five also in Jan-May 2017.

5.2 Ozone Episodes

There were three periods when ozone concentrations in Northern Ireland reached 'Moderate' levels:

- 24th – 25th April. The Met Office air quality notification forecast that dry and sunny conditions, combined with light winds, would allow large areas of Moderate air pollution to develop.
- 6th – 7th May. The Met Office again attributed this to warm, sunny weather – noting that the ongoing fine conditions had led to peak diurnal ozone concentrations rising through the week.
- 28th – 31st May. This was also attributed by the Met Office to the fine, warm and sunny weather.

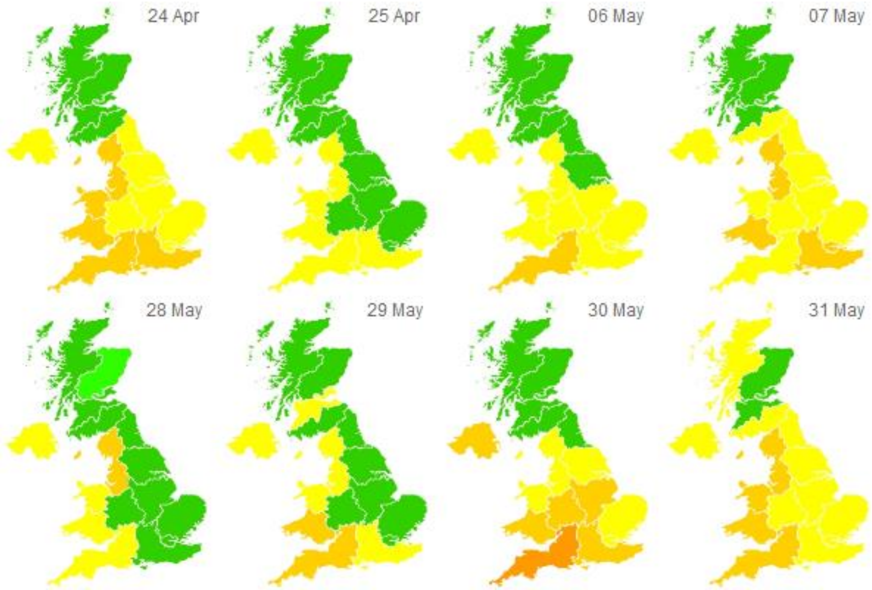
Table 5-2 shows the maximum daily mean ozone concentration at Northern Ireland's three monitoring sites on these days. The numbers in red indicate measured daily maximum O_3 concentration above the lower threshold of the Moderate band, 100 μgm^{-3}.

Table 5-2 Days when ozone reached the moderate band – numbers in red represent measured daily max 8-hour ozone levels above 100 µgm^{-3} (moderate band threshold.

	Daily Max 8Hour Ozone (µgm^{-3})		
Date	**Belfast Centre**	**Derry Rosemount**	**Lough Navar**
24/04/2020	91	87	119
25/04/2020	89	77	110
06/05/2020	95	95	103
07/05/2020	101	81	90
28/05/2020	84	91	103
29/05/2020	110	105	111
30/05/2020	100	106	121
31/05/2020	108	109	118

The maps in Figure 5-2 show how these pollution episodes were not isolated to Northern Ireland, but affected all of Wales, large parts of England and in some cases parts of Scotland.

Figure 5-2 Maps Showing DAQI for periods with moderate ozone (Source: UK-AIR)



The main cause of these PM and ozone episodes appears to have been the weather conditions at the time: dry, warm and sunny – typical conditions for summer type pollution episodes, particularly ozone. Ozone and particulate matter pollution episodes are common in the spring and summer.

In total, there were eight days during the period 1st January to 31st May 2020 exceeded the lower threshold of the 'Moderate' band in Northern Ireland. This is consistent with the same period in previous recent years: there were nine such days in Jan-May 2019, ten in Jan-May 2018 and five in Jan-May 2017.

6 Analysis of Changes in Pollutant Concentrations

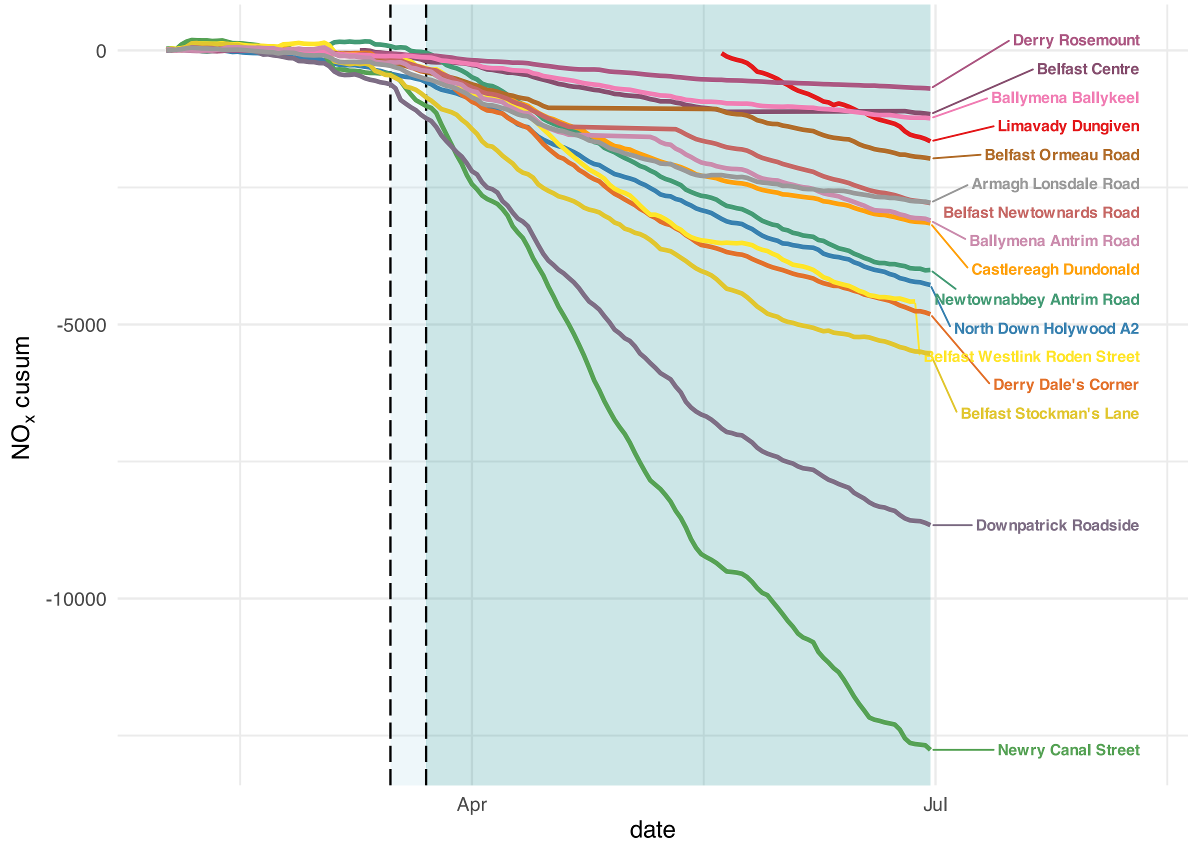
6.1 Analysis of Changes in Total NO_X Concentration

Figure 6-1 shows a time series of daily mean concentrations of total NO_X ($NO + NO_2$) at a range of air pollution monitoring sites across Northern Ireland from 1st February 30th June 2020. Light blue shading (between the vertical dashed lines) indicates the period between the start of social distancing on 16th March: darker blue shading indicates the period from 23rd March when lockdown was in place.

Figure 6-1 Daily mean concentrations of NO_X at a range of air pollution monitoring sites across Northern Ireland from 1st February 30th June 2020.

In general, it can be difficult to tell from this plot alone whether concentrations changed by much when lockdown started. A clearer indication of the changes in concentrations can be seen from the cusum plot shown in Figure 6-2. This shows the cumulative sum (cusum) of measured minus business as usual NO_X at the same air pollution monitoring sites across Northern Ireland. Again, light blue shading shows the period of recommended social distancing from 16th March, and the dark shading shows the period from the start of the lockdown on 23rd March. Most of the lines' gradients tend to become negative around the lockdown period, although Downpatrick Roadside and Newry Canal Street show some indication of decreases ahead of the lockdown date. (Flat sections of line correspond to gaps in the dataset e.g. for Belfast Ormeau Road.) What is clear from Figure 6-2 is that all sites show some decrease in NO_x concentration – and there is a wide range of behaviours. Overall, there is compelling evidence that concentrations of NO_x decreased across a wide range of sites and the timing of the decrease was around the lockdown date.

Figure 6-2 The cumulative sum (cusum) of measured minus business as usual NOx concentration at a range of air pollution monitoring sites across Northern Ireland.

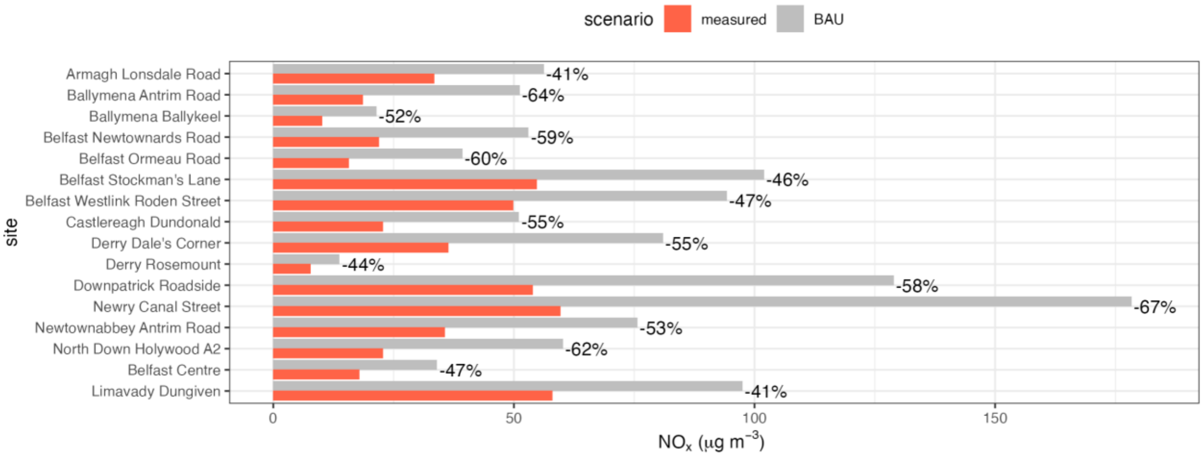


In terms of absolute changes to concentrations of NO_x by site, Figure 6-3 summarises the comparison between measured concentrations and BAU, for the period 23rd Mar – 30th Jun. The numbers show the percentage change in concentration relative to business as usual. Reductions ranged from 41% to 67%. On average, over the lockdown period until the end of June, NO_x concentrations were 52% lower than usual, corresponding to an absolute reduction of 37 µg m^{-3}. Both roadside and urban background monitoring sites measured clear decreases in NO_x.

The Air Quality Expert Group (AQEG), in their Rapid Evidence Review, reported mean reductions of typically 30-40% in urban NO_x for the UK as a whole (Air Quality Expert Group, 2020). It appears reductions have been greater in Northern Ireland.

In section 3.2.3, it was estimated that road traffic contributes just under 30% of Northern Ireland's total NO_x emissions, and that traffic counts dropped by around two-thirds immediately following the onset of lockdown, possibly resulting in a short-term reduction of 20% in Northern Ireland's NO_x emissions. However, it was predicted that the reduction in measured ambient concentrations could well be greater, especially at roadside sites where traffic emissions contribute a high proportion of ambient NO_x. On the basis of the analysis carried out here, this appears to be the case.

Figure 6-3 Measured and estimated business as usual NOx concentrations by site. The numbers show the percentage change in concentration relative to business as usual.



6.2 Analysis of Changes in NO_2 Concentration

Nitrogen dioxide is of particular interest as several sites in Northern Ireland have exceeded applicable limit values or objectives for this pollutant in recent years. Four urban roadside sites (Belfast Stockman's Lane, Downpatrick Roadside, Limavady Dungiven and Newry Canal Street) had annual mean NO_2 concentrations above the Air Quality Strategy (AQS) Objective of 40 µg m^{-3} in 2019.

Figure 6-4 shows a time series of daily mean concentrations of NO_2 at a range of air pollution monitoring sites across Northern Ireland from 1st February 30th June 2020. Light blue shading indicates the period between the start of social distancing on 16th March: darker blue shading indicates the period from 23rd March when lockdown was in place. Figure 6-5 shows the cumulative sum (cusum) of measured minus business as usual NO_X at the same air pollution monitoring sites across Northern Ireland. Again, shading is used to mark the onset of social distancing and lockdown. The change in NO_2 concentration is clearer than that seen for NO_x: this is best seen in the cusum plot (Figure 6-5).

Figure 6-4 Daily mean concentrations of NO_2 at a range of air pollution monitoring sites across Northern Ireland from 1st February 30th June 2020.

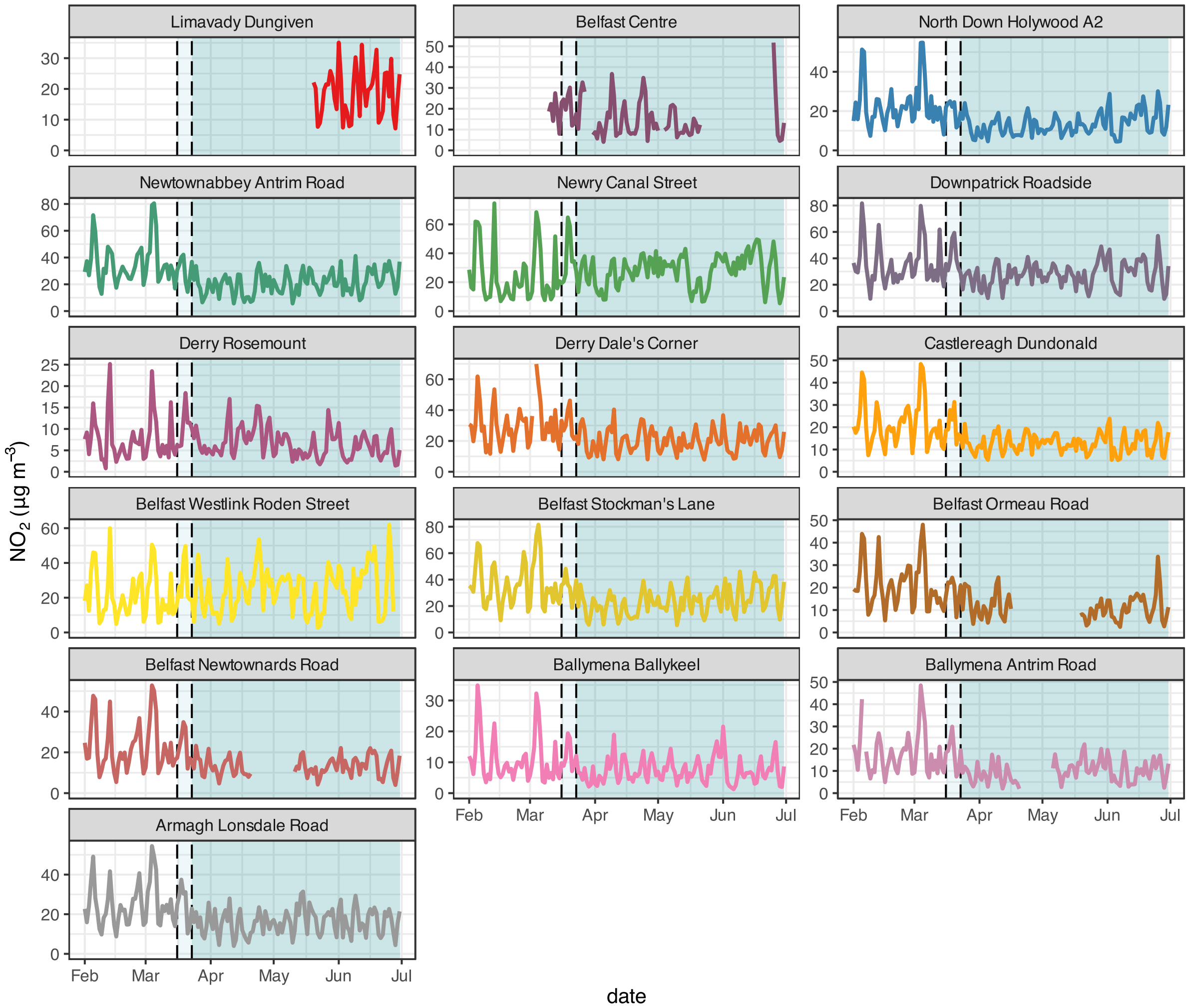


Figure 6-5 The cumulative sum (cusum) of measured minus business as usual NO_2 at a range of air pollution monitoring sites across Northern Ireland.

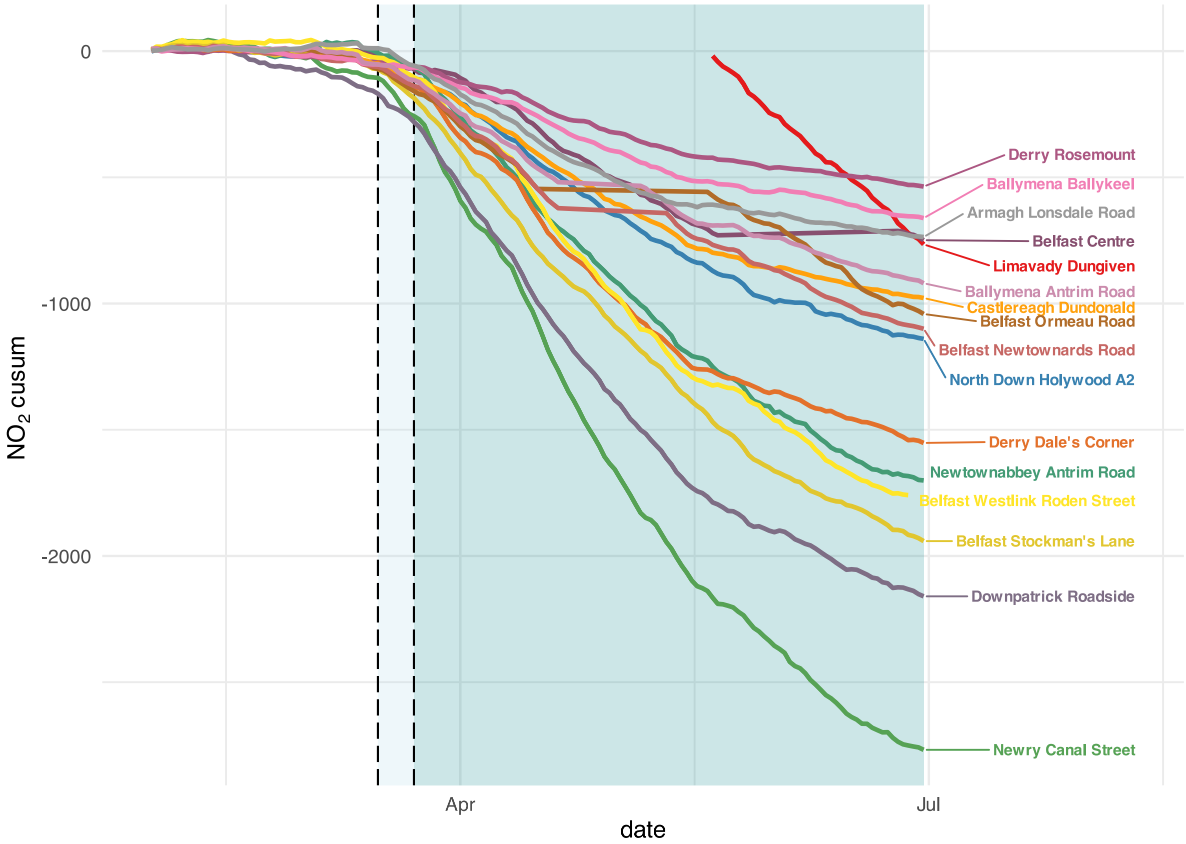
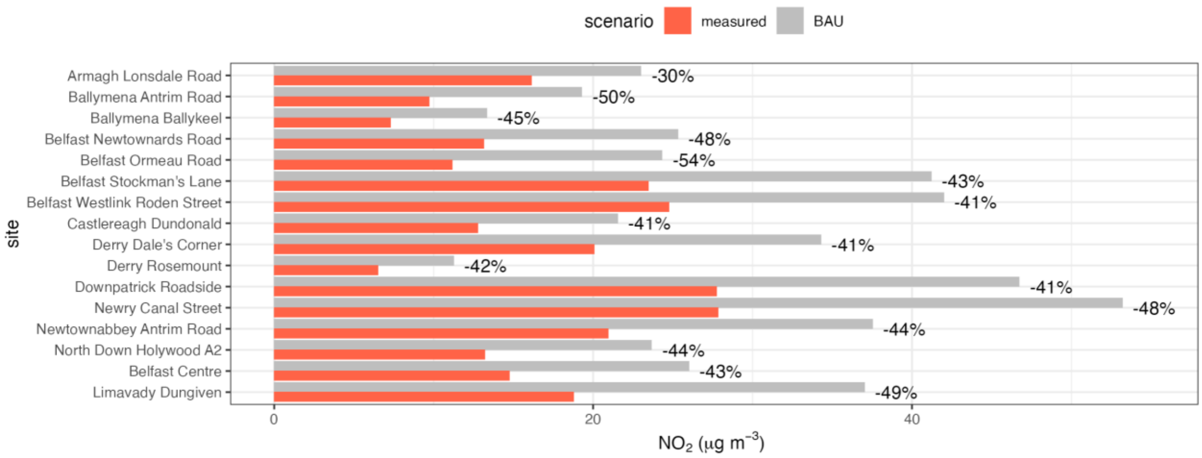


Figure 6-6 summarises the comparison between measured concentrations and BAU. Averaged across all sites, over the period from the beginning of lockdown to the end of June, NO_2 concentrations were 44% lower than BAU (ranging from 30% to 54% lower). This corresponds to an absolute average change of 13 µg m^{-3}.

At Belfast Stockman's Lane, Downpatrick Roadside and Newry Canal Street, the BAU NO_2 concentrations exceeded the AQS objective of 40 µg m^{-3}: however, average measured concentrations at these sites during the lockdown period were reduced to less 30 µg m^{-3}.

The AQEG Rapid Evidence Review (Air Quality Expert Group, 2020) reported mean reductions in NO_2 concentration typically in the range of 20-30% for the UK as a whole: the reductions reported here for Northern Ireland appear larger.

Figure 6-6 Measured and estimated business as usual NO_2 concentrations by site. The numbers show the percentage change in concentration relative to business as usual.



6.3 Analysis of Changes in Ozone Concentration

Ozone is measured at three locations in Northern Ireland (see Table 2-1): Lough Navar (remote rural) Belfast Centre (urban centre), Derry Rosemount (urban background). A time series of daily mean O_3 concentrations is shown in Figure 6-7. Again, light blue shading shows the period from the start of social distancing on 16th March and darker blue shading shows the lockdown period from 23rd March. These time series show no clear change in O_3 concentration at the introduction of lockdown.

However, the cusum plot (Figure 6-8) gives a much clearer impression. At the rural site of Lough Navar, there is very little evidence that concentrations changed due to lockdown. In contrast, Belfast Centre and Derry Rosemount show clear evidence of an *increase* in O_3 concentrations since lockdown.

Figure 6-9 compares measured concentrations during the lockdown period with the 'business as usual' predictions. Belfast Centre and Derry Rosemount showed increases of 23% and 20% respectively, while Lough Navar showed a much smaller increase of just 3%.

Ozone concentrations exhibit seasonal variation, typically being higher in the summer months. So an increase in O_3 concentrations during April and May might be expected, simply on the basis of the usual seasonal pattern for this pollutant. As highlighted in sections 4 and 5.2 above, there were significant ozone episodes, driven by meteorology, during the lockdown period. However, if this was the only reason for the observed increase, a similar increase might be seen at the rural Lough Navar site, which is not the case.

A possible explanation of why O_3 increased more at the urban sites than at the rural site (compared to the BAU scenario) is because urban concentrations of NO_x decreased. Because O_3 is removed by reaction with NO, reducing NO_x emissions will tend to result in a commensurate increase in O_3.

The behaviour described above may be important from a public health perspective i.e. what is the impact of a reduction in NO_2 but an increase in O_3? These changes also highlight why it would be difficult to conclude that air quality overall has improved, as it depends on the pollutant in question. Indeed, there are arguments for considering the sum of O_3 and NO_2 for health impact studies because NO_2 and O_3 readily interconvert in the atmosphere (Williams, M. L., et al., 2014). On this basis, the sum of O_3 and NO_2 changed very little in urban areas of Northern Ireland due to lockdown.

Figure 6-7 Daily mean concentrations of O_3 at three air pollution monitoring sites in Northern Ireland from 1st February to 30th June 2020.

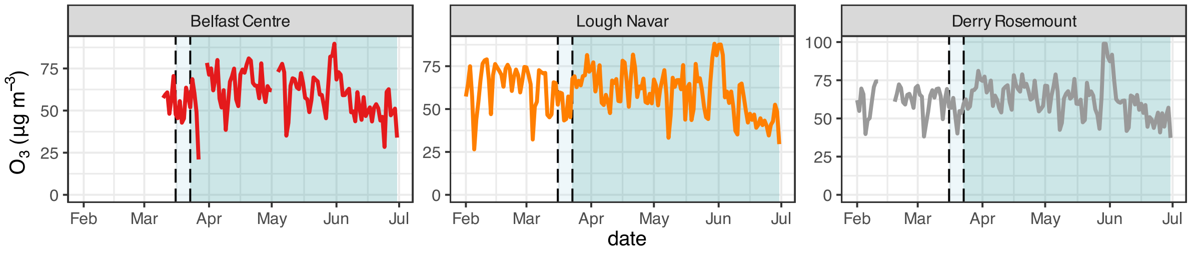


Figure 6-8 The cumulative sum (cusum) of measured minus business as usual O_3 at three pollution monitoring sites across Northern Ireland.

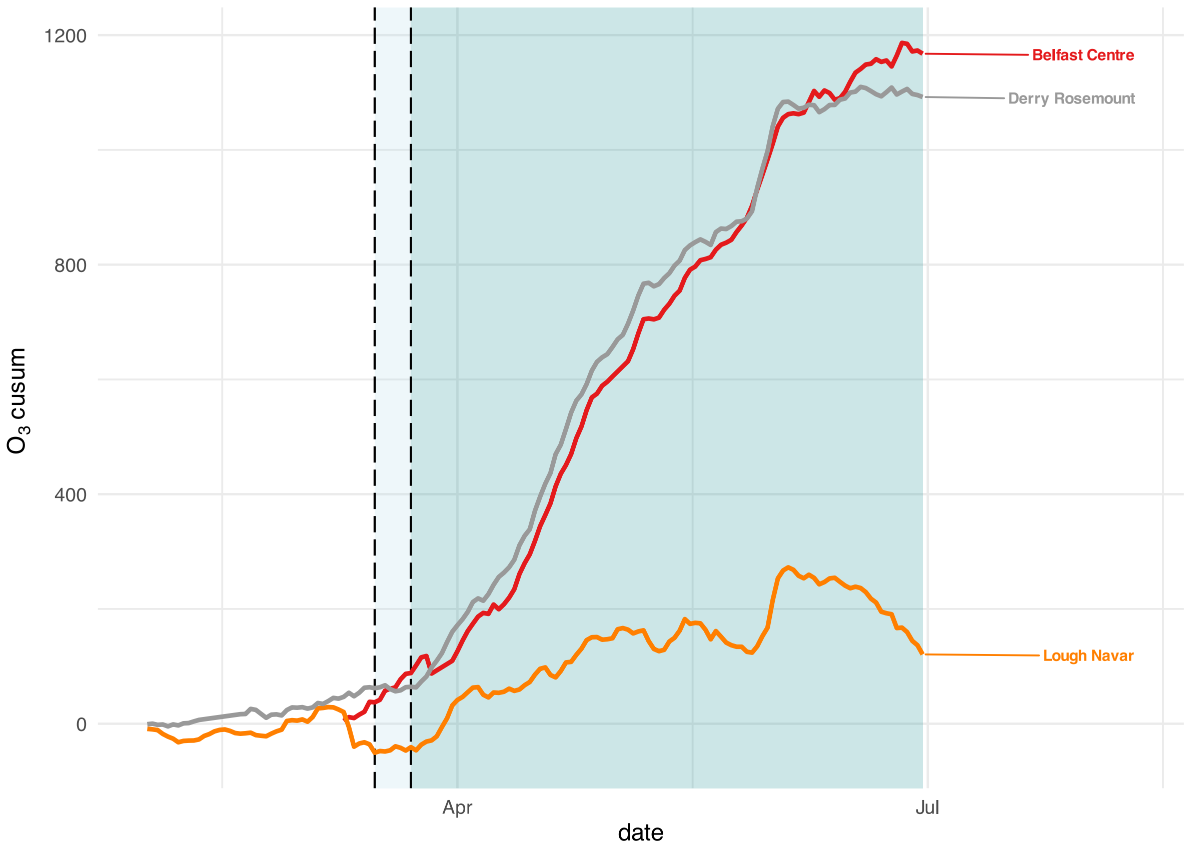
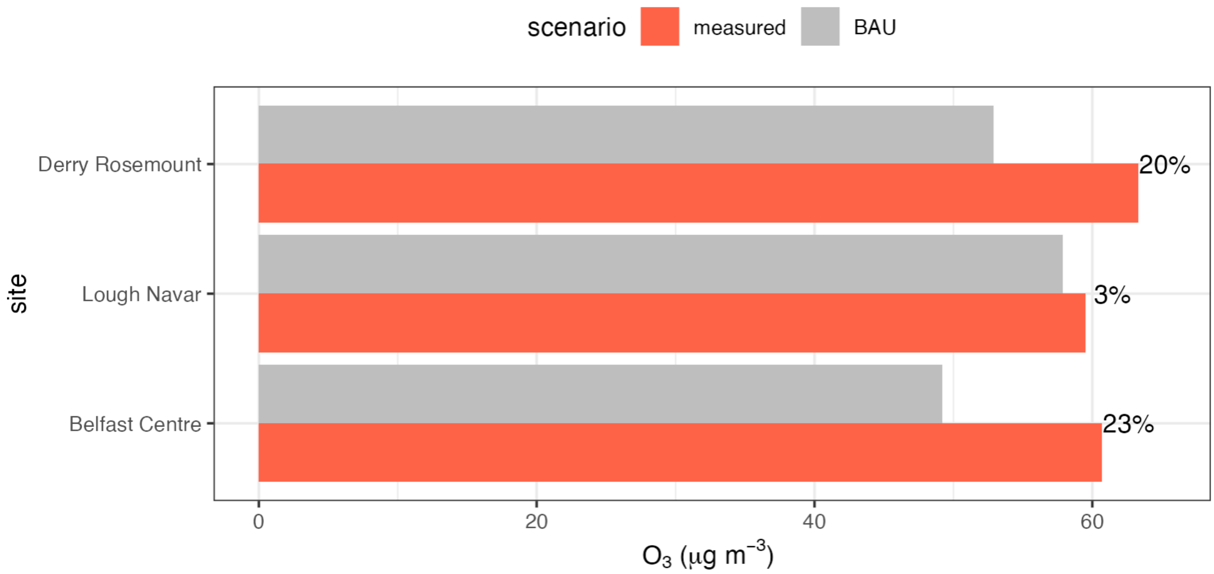


Figure 6-9 Measured and estimated business as usual O_3 concentrations by site. The numbers show the percentage change in concentration relative to business as usual.



The AQEG Rapid Evidence Review (Air Quality Expert Group, 2020) also reported that increased ozone had been observed at some UK urban monitoring stations, and attributed this to lower local NO emissions. The findings for Northern Ireland are consistent with this.

In summary, the data presented in this section indicate that ozone concentrations in urban areas during the lockdown period were higher than predicted under the BAU scenario. It is suggested this may be due to the observed lower concentrations of NO_X, as NO 'scavenges' O_3 – i.e. removes it from the ambient air by reacting with it. Therefore, although the ozone episodes were transboundary events largely driven by seasonal meteorological conditions, it is likely that the reduction in NO emissions (due to reduced road traffic) allowed urban O_3 concentrations to become higher than they otherwise would. Based on the data in section 6.3, it is possible that this effect made the difference between urban O_3 remaining in the 'Low' band, and rising into the 'Moderate' band as it did.

Despite the evidence that reduced NO concentrations may have exacerbated urban ozone levels, it would be a mistake to conclude that NO_X emissions are a good thing, or that no effort should be made to control them. Oxides of nitrogen are involved in the formation of ozone as well as its removal, and have health impacts of their own. Besides, many sources of NO_X also emit other harmful pollutants such as particulate matter and SO_2.

6.4 Analysis of Changes in PM_{10} Concentration

The analysis of PM_{10} concentrations is much more challenging that the other pollutants considered so far. This is because PM_{10} concentrations tend to be dominated by regional background levels rather than local primary emissions. Accounting for the variation due to the weather is therefore more challenging because the concentrations will tend to be largely controlled by regional scale processes rather than local meteorology. A further possible complication is that several of Northern Ireland's PM_{10} monitoring sites have had changes in instrumentation or methodology, over the past two years. Nevertheless, Northern Ireland does have a large number of PM_{10} measurement sites that can be considered.

To analyse the PM_{10} data and better understand the effects on local emissions, we have compared PM_{10} concentrations measured at Northern Ireland's urban sites with those measured at the rural background site at Lough Navar (that is, the ***urban increment*** in PM_{10}). This approach will provide a better opportunity to consider changes to locally derived concentration contributions that are affected by meteorology in much the same way as pollutants such as NO_x and SO_2.

Figure 6-10 shows daily mean concentrations of the urban increment in PM_{10} concentration above regional background (Lough Navar) at a range of air pollution monitoring sites across Northern Ireland from 1st February to 30th June 2020. The light blue shading shows the period from 16th March, when social distancing was first recommended. The darker blue shading shows the period from the start of the 'lockdown' that began on the 23rd March.

Figure 6-10 Daily mean concentrations of the increment in PM_{10} concentration above regional background (Lough Navar) at a range of air pollution monitoring sites across Northern Ireland from 1st February to 30th June 2020.

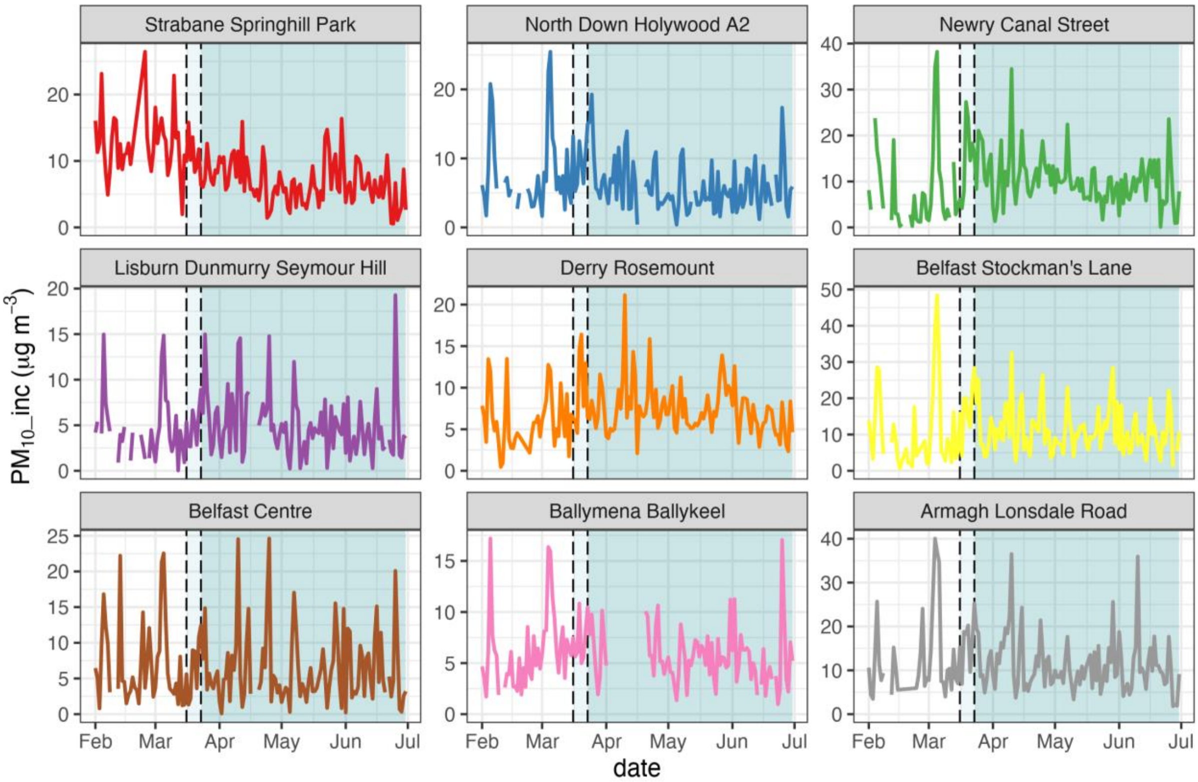


Figure 6-11 shows the cumulative sum (cusum) of measured minus 'business as usual' for the increment in PM_{10} concentrations above regional background (Lough Navar) at the same monitoring sites. Again, lighter and darker blue shading indicate the points where social distancing and lockdown began.

The cusum plot reveals some interesting, contrasting behaviours in how the increment in PM_{10} changed over lockdown. Some sites show an increase in concentration (Derry Rosemount, Armagh Lonsdale Road and Belfast Stockman's Lane) and some show a decrease in PM_{10} (Strabane Springhill Park, Belfast Centre and Newry Canal Street).

Figure 6-12 shows measured PM_{10} increment above regional background (Lough Navar), compared to estimated BAU concentrations by site. The numbers show the percentage change in concentration relative to BAU. The average increase in PM_{10} overall was around 1 µg m^{-3} BAU. For this reason, the changes in PM_{10} should be considered as uncertain compared with the changes seen for other pollutants. Also, as highlighted above, the situation for PM_{10} may also have been complicated by some changes in monitoring methods during 2019 and 2020.

Figure 6-11 Cusum plot of measured minus business as usual for the increment in PM_{10} concentrations above regional background (Lough Navar) at a range of air pollution monitoring sites across Northern Ireland.

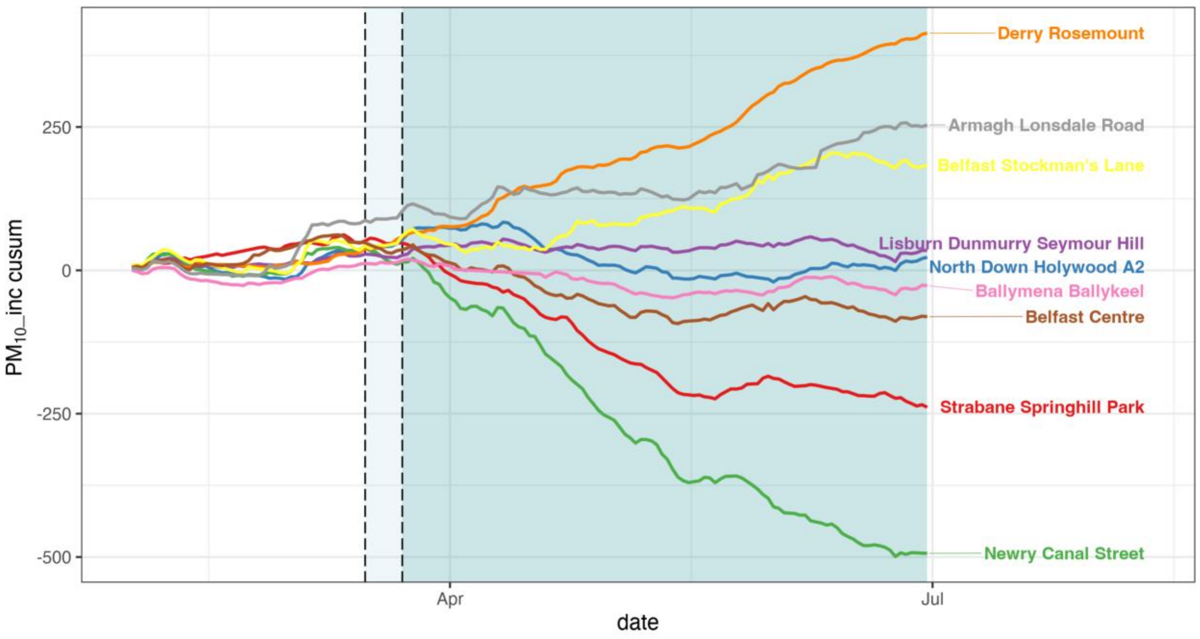
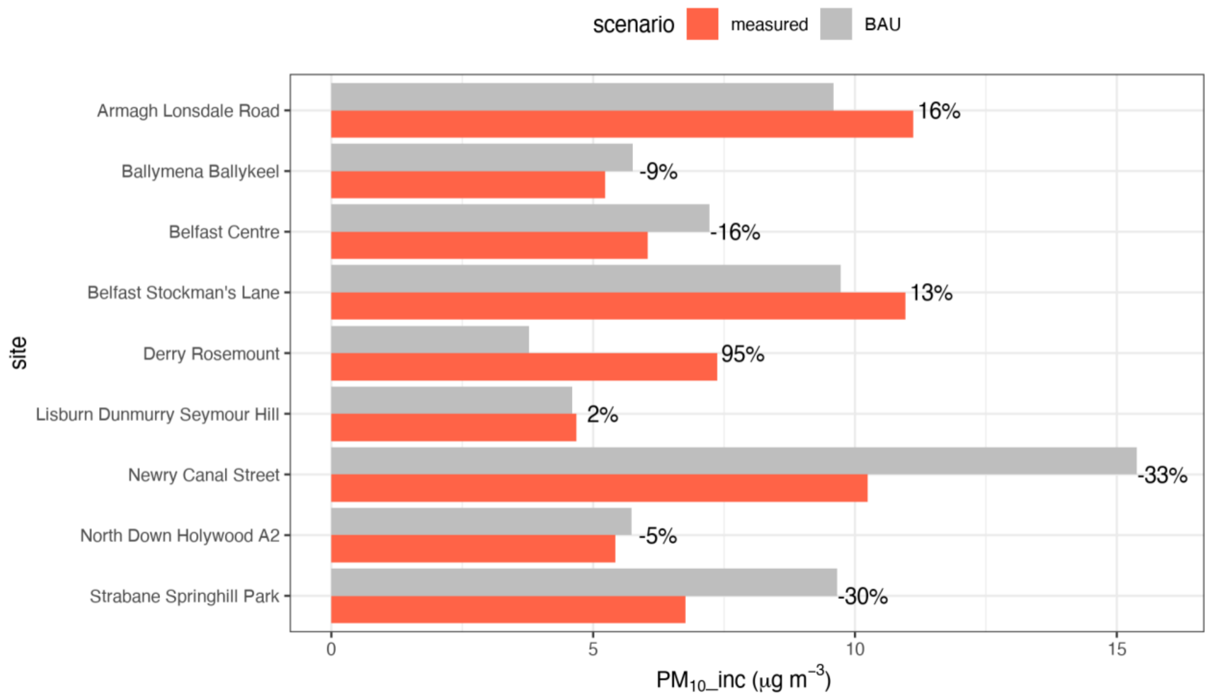


Figure 6-12 Measured and estimated business as usual in the PM_{10} increment above regional background (Lough Navar) concentrations by site.



Unfortunately, it has not been possible to carry out the same type of analysis for $PM_{2.5}$. Calculating the 'urban increment' – the difference between urban concentrations and the regional background – is essential in the case of PM_{10}, and even more so in the case of $PM_{2.5}$, as $PM_{2.5}$ is dominated by the regional background. Although $PM_{2.5}$ is measured at three sites in Northern Ireland (Belfast Centre, Derry Rosemount and Lough Navar), only one (Lough Navar) is rural, and this site only began monitoring $PM_{2.5}$ relatively recently, in July 2018. Therefore, there is insufficient rural $PM_{2.5}$ data to allow a similar analysis to be carried out for this pollutant, as the BAU scenario cannot be modelled robustly.

The AQEG Rapid Evidence Review (Air Quality Expert Group, 2020) reported that "*Meteorological conditions have led to higher $PM_{2.5}$ during lockdown than the average experienced in equivalent calendar periods from previous years*" – but also that in southern England at least, average concentrations were still 2-5 µg m^{-3} lower than they would have been under BAU.

6.5 Analysis of Changes in Black Carbon Concentration

Four sites in Northern Ireland measure black carbon (BC). Figure 6-13 shows daily mean concentrations of BC at these sites from 1st February to 30th June 2020. As in previous charts, light blue shading shows the period from the start of social distancing on 16th March, and darker blue shading shows the period from the start of lockdown on 23rd March. Unfortunately, two of the four sites have significant amounts of missing data, but are shown for completeness. Kilmakee Leisure Centre and Strabane 2 (which is referred to as 'Strabane Springhill Park' in other networks) do have complete time series.

Figure 6-14 shows a cusum plot of measured minus BAU black carbon at the four sites. Strabane 2 in particular shows strong evidence of a decrease in BC concentrations, whereas Kilmakee only shows weak evidence of a decrease. It is interesting that the same site (as Strabane Springhill Park) also showed a decrease in PM_{10} concentration (Figure 6-11).

Figure 6-13 Daily mean concentrations of BC at four monitoring sites in Northern Ireland from 1st February to 30th June 2020.

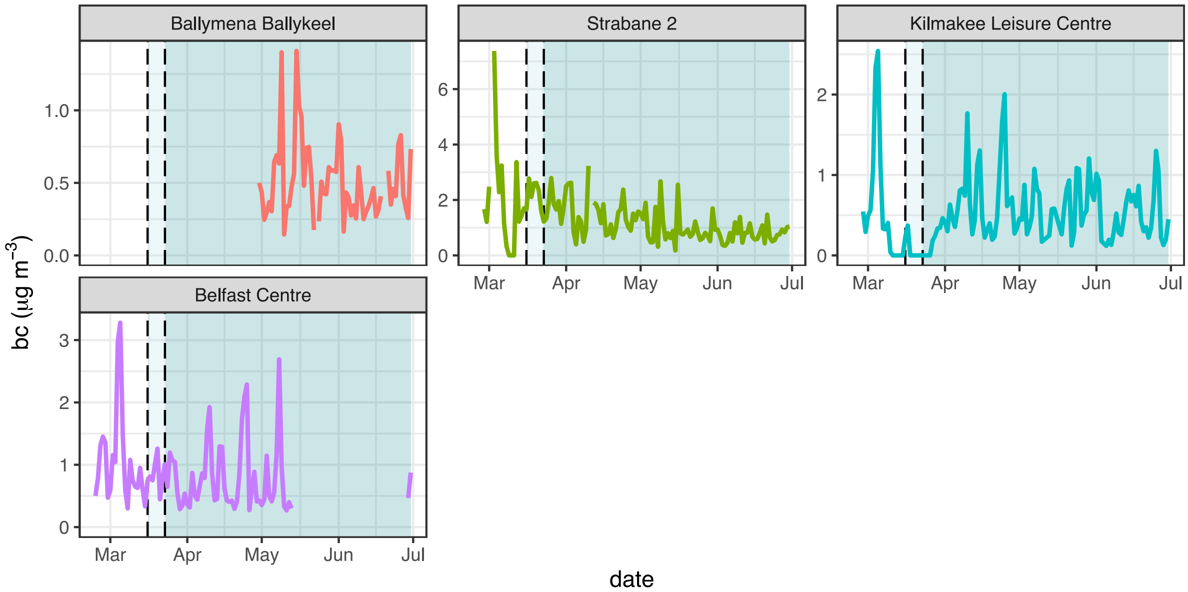
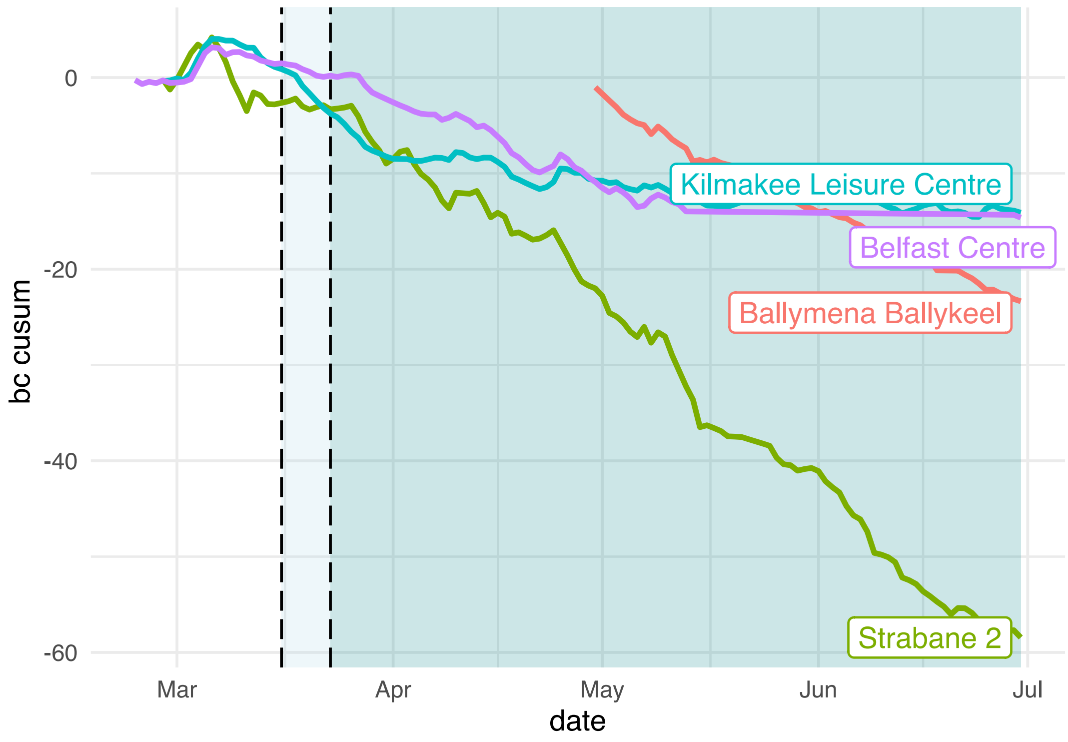


Figure 6-14 The cumulative sum (cusum) of measured minus business as usual BC at four monitoring sites in Northern Ireland. (Flat line for Belfast Centre indicates missing data.)



6.6 Analysis of Changes in SO_2 Concentration

Sulphur dioxide concentrations showed a mixed response to the lockdown. As for the other pollutants considered, it is difficult to tell from the time series of daily means alone (Figure 6-15) how concentrations have changed.

Figure 6-16 shows the cusum of measured minus BAU SO_2 concentration, at Northern Ireland's four SO_2 monitoring sites. (The fifth site, Ballymena Ballykeel, has been excluded due to low data capture). The light blue shading shows the period of recommended social distancing from 16th March, the darker blue shading shows the period from the start of the lockdown on 23rd March. The cusum plot reveals differing behaviours depending on the site. At Belfast Centre and Derry Rosemount there is little evidence that SO_2 concentrations changed over the period considered. However, at Strabane Springhill Park, there is evidence that SO_2 increased. In contrast, concentrations at Lisburn Dunmurry Seymour Hill apparently decreased.

Figure 6-17 compares average measured and estimated BAU SO_2 concentrations by site. The numbers show the percentage change in concentration relative to business as usual.

It is interesting to compare the changes in SO_2 concentration with those for PM_{10}, as both pollutants can be associated with combustion of fuels such as coal and oil. Two sites showed differing patterns for these two pollutants:

- Lisburn Dunmurry Seymour Hill showed a marked decrease in SO_2, in contrast to a marked increase in PM_{10} increment compared to the rural background.
- Strabane Springhill Park showed an apparent increase in cusum SO_2 despite a decrease in both PM_{10} urban increment and black carbon.

Concentrations being measured are very low, in most cases close to the limit of detection of the method. This is challenging for the instrumentation. In particular, the ultraviolet fluorescence analyser used to monitor SO_2 can exhibit drift, causing an apparent (and false) upward trend. This can be adjusted for, as part of the data ratification process. It is therefore recommended that the findings for SO_2 in particular are reviewed when the ratified dataset is available.

Figure 6-15 Daily mean concentrations of SO_2 at five monitoring sites across Northern Ireland from 1st February 30th June 2020.

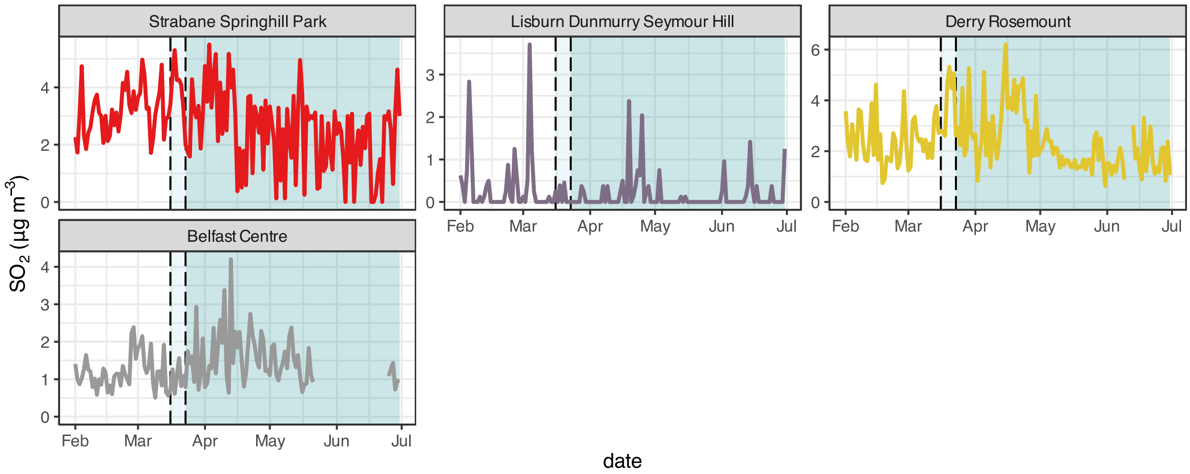


Figure 6-16 The cumulative sum (cusum) of measured minus business as usual SO_2 at a five monitoring sites across Northern Ireland.

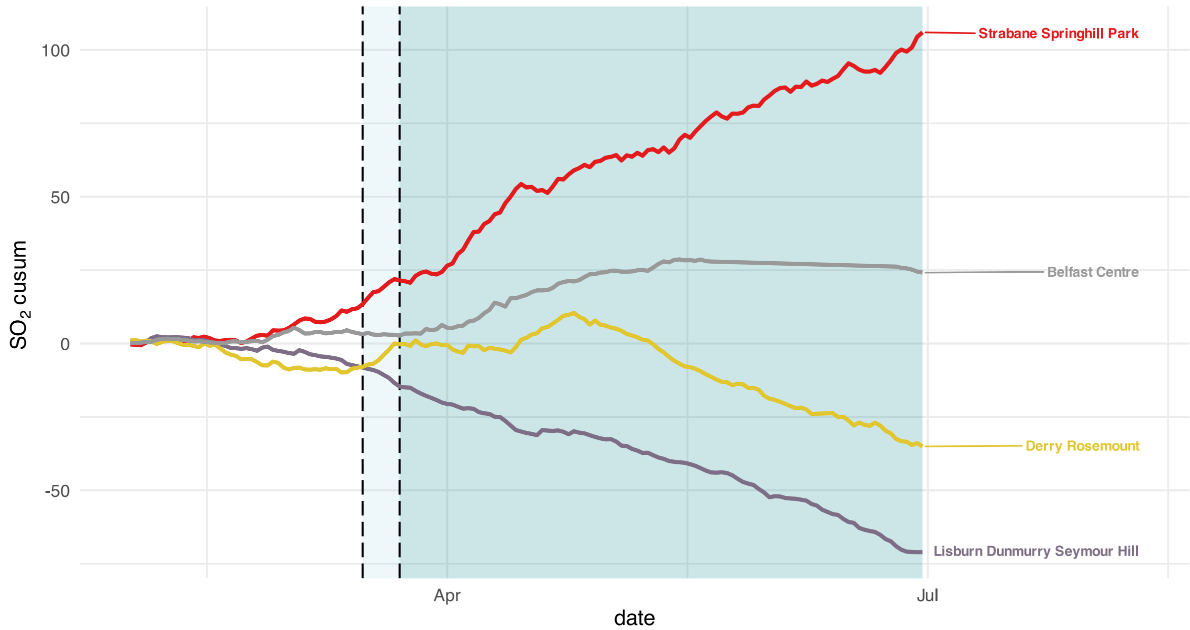
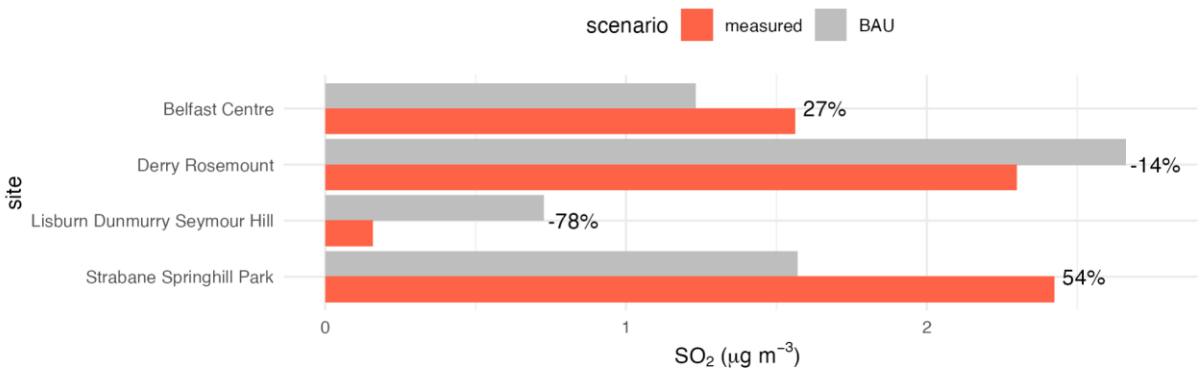


Figure 6-17 Measured and estimated business as usual SO_2 concentrations by site. The numbers show the percentage change in concentration relative to business as usual.



6.7 Analysis of Changes in Carbon Monoxide Concentration

Although CO emissions from road vehicles (particularly petrol engine cars) have decreased in recent decades, this still remains a significant source of CO in Northern Ireland. Ambient CO concentrations might therefore be expected to show evidence of changes in road vehicle activity.

Carbon monoxide is monitored at one site in Northern Ireland: Belfast Centre. Daily mean CO concentrations from this site are shown in Figure 6-18, and indicate some evidence of a reduction around the start of lockdown, with concentrations returning to their previous levels during June.

The timing of the change in concentrations is more clearly seen in Figure 6-19, which shows the cusum plot. In this figure, it is clear that concentrations began to decrease around lockdown, as did those of NO_x and NO_2. Overall, lockdown is estimated to have reduced concentrations of CO as measured at this site by about 45%, as shown in Figure 6-20.

Figure 6-18 Daily mean concentrations of CO at Belfast Centre from 1st February to 30th June 2020. The light blue shaded area shows the period from 16th March, when social distancing was first recommended. The darker shaded area shows the period from the start of 'lockdown' on 23rd March.

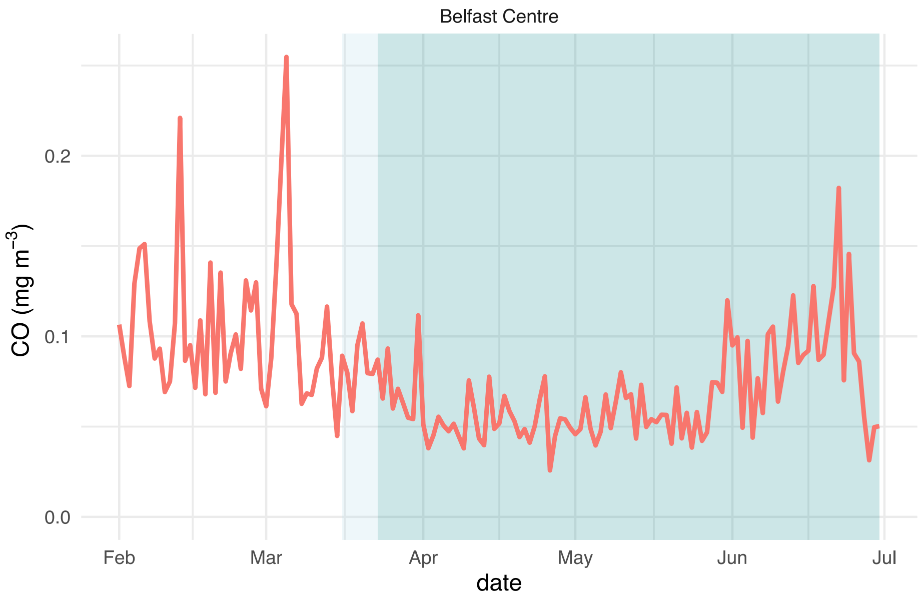


Figure 6-19 The cumulative sum (or cusum) of measured minus business as usual CO at Belfast Centre. The light blue shaded area shows the onset of social distancing from 16th March, the darker shaded area shows the 'lockdown' period starting 23rd March.

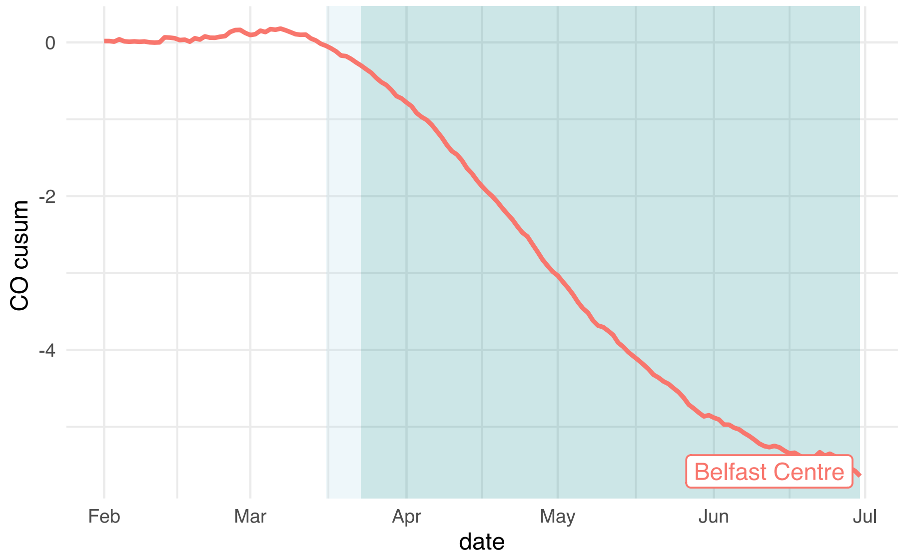
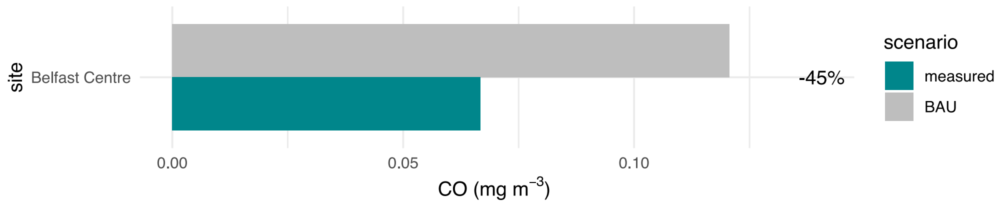


Figure 6-20 Measured and estimated BAU CO concentrations at Belfast Centre. The numbers show the percentage change in concentration relative to business as usual.



7 Changes in Diurnal Variation in NO_X and PM_{10}

This section reviews how the lockdown appears to have changed diurnal patterns in pollutant concentrations, for the following:

- Oxides of nitrogen (total NO_X) at roadside monitoring sites
- PM_{10} at roadside and urban background monitoring sites.

Figure 7-1 shows diurnal variation in average weekday hourly mean NO_X concentration for 12 roadside monitoring sites. Four years are compared: 2017 to 2020. For all sites, the average NOx levels during the weekdays were lower in 2020, compared to previous years. At some sites, such as Downpatrick Roadside and North Down Holywood A2, the morning 'rush hour' peak was also less pronounced in 2020, compared to previous years.

Figure 7-2 shows a comparison of the hourly variation in NOx for the periods before and after social distancing measures were implemented on 16th March. This chart compares the period 1st February – 15th March 2020 with 16th March - 30th April 2020. Peaks in NOx, observed during rush hour periods in the morning and evening prior to 16th March, are much lower after this date, and at some sites there is little evidence of any evening rush hour peak in NOx. This may be the result of a change in working patterns, and fewer vehicles on the roads.

The morning peak also occurs approximately an hour earlier in the 16th March – 30th April graph: however, this is probably due to the change from GMT to British Summer Time (BST) at the end of March.

Figure 7-1 Average weekday diurnal variability in NOx for April, May, and June from 2017 to 2020, measured at roadside monitoring sites across Northern Ireland. (Times are GMT).

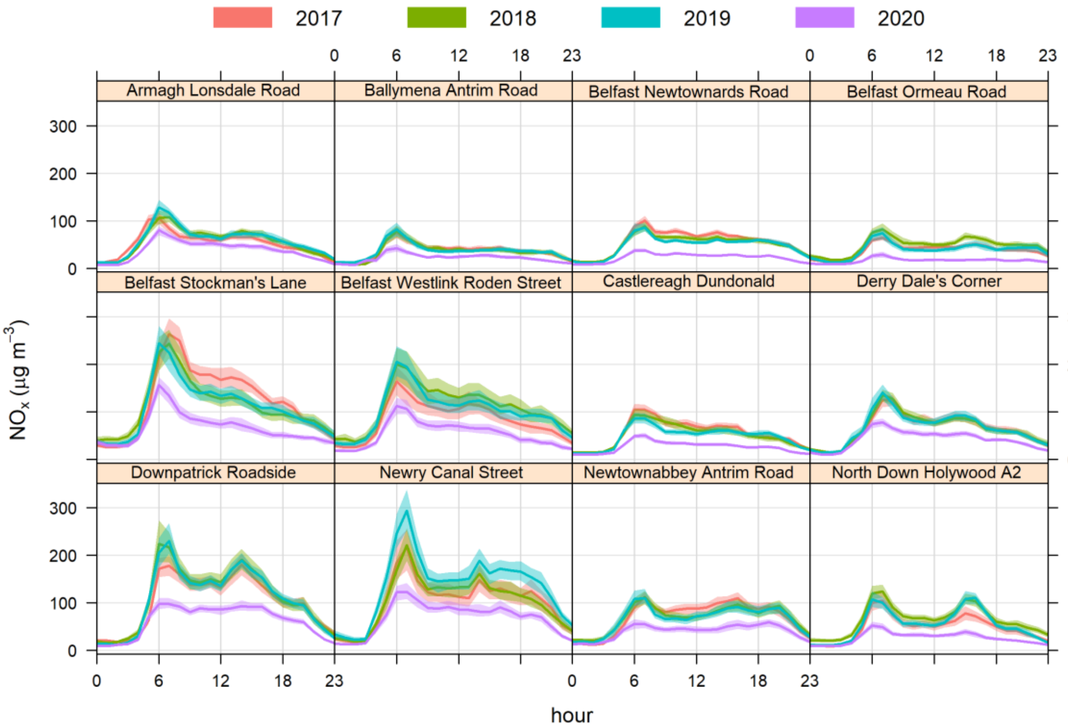
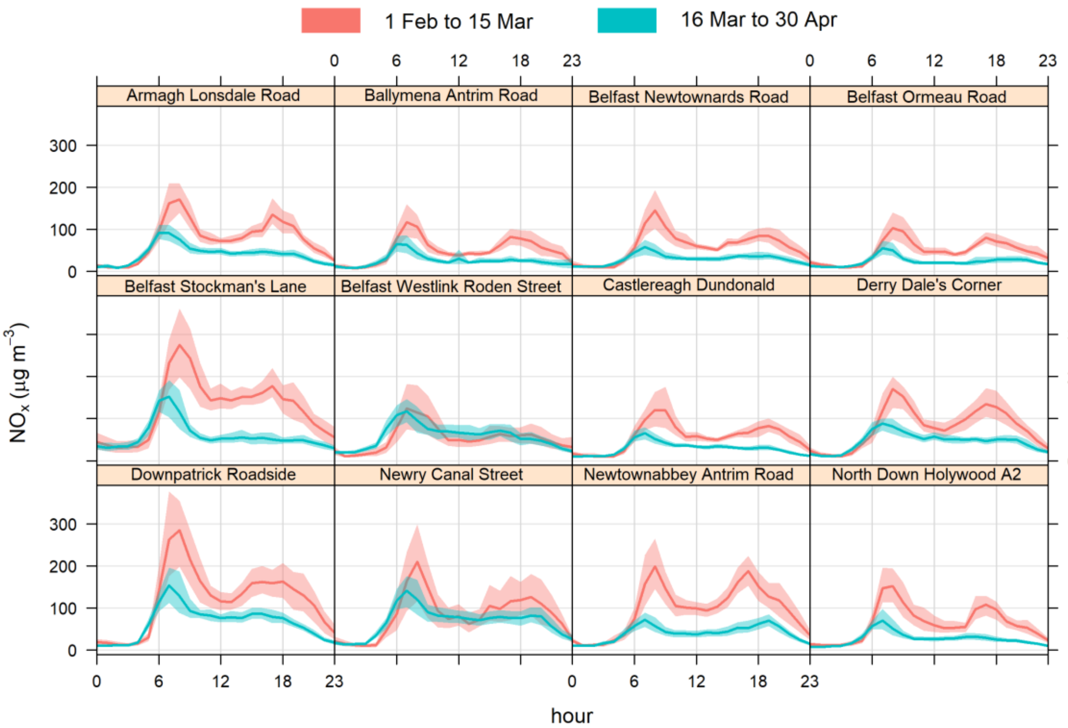


Figure 7-2 Average weekday diurnal variability in NOx for the periods 1st February to 15th March 2020, and 16th March to 30th April 2020, measured at roadside monitoring sites across Northern Ireland. (Times GMT)



For PM_{10} rural background concentrations from the Lough Navar rural site were first subtracted from the roadside measurements, before averaging, to calculate the urban increment diurnal variation in

PM_{10}. This is consistent with the approach used in section 4. Figure 7-3 shows that there are no clear differences observed in the average diurnal weekday variation in the PM_{10} urban increment for April to June in 2020, when compared to the same period in previous years, at four roadside monitoring sites.

However, when comparing the few weeks before and after social distancing was implemented, as shown in Figure 7-4, there is some evidence in a shift in the pattern of the diurnal cycles. After 16th March, the morning peak in PM_{10} appears to be slightly earlier in the morning. As in the case of NO_X, this probably reflects (at least in part) the change from GMT to BST at the end of March. However, there may also be some changes to traffic patterns in the urban areas – for example, with schools closed there may have been no 'school run' traffic. Also it should be noted that for both NOx and PM_{10}, variations due to changes in meteorology are not considered in the analysis here.

Figure 7-3 Average weekday diurnal variation in the urban PM_{10} increment at urban roadside monitoring sites across Northern Ireland, for April, May, and June from 2017 to 2020. (Times GMT).

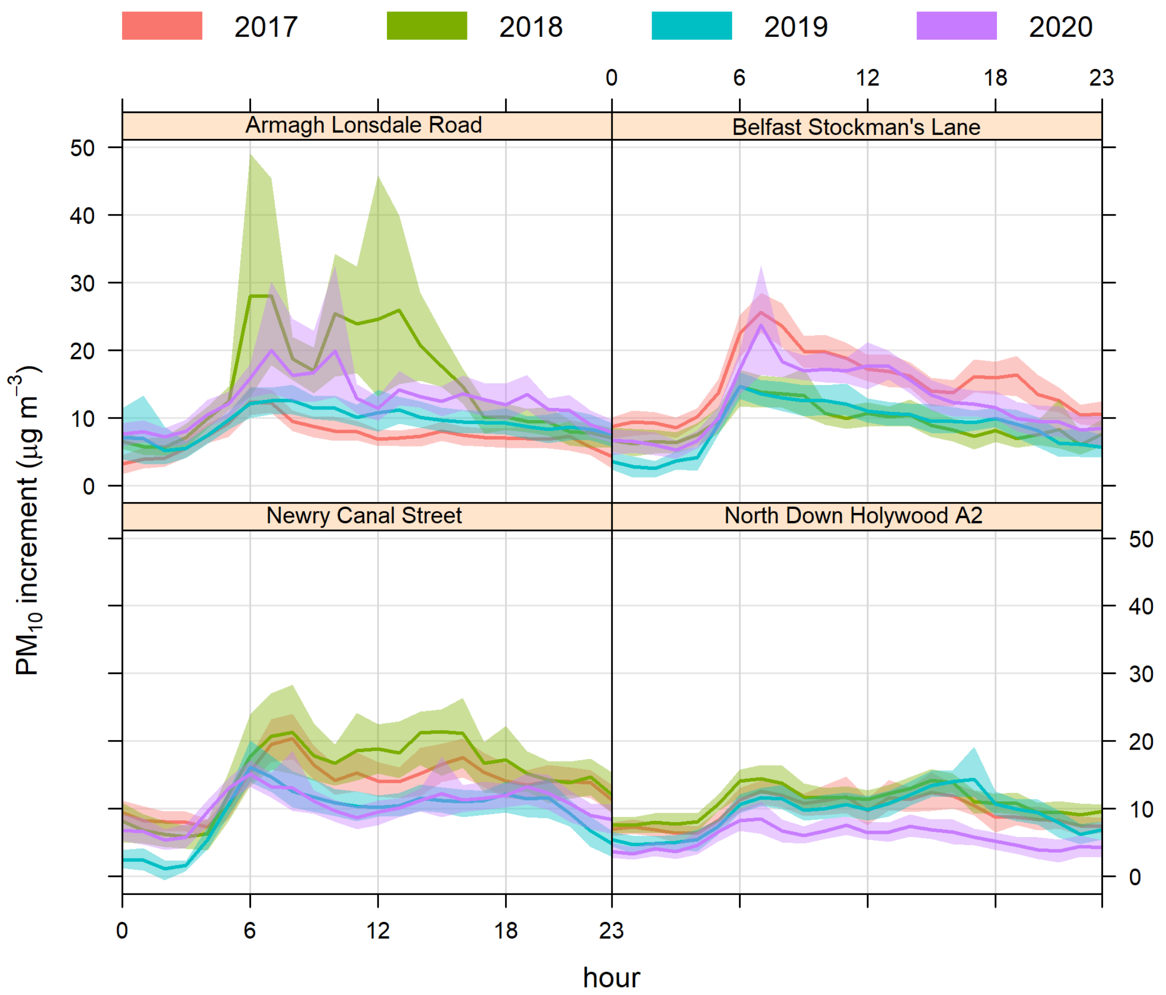
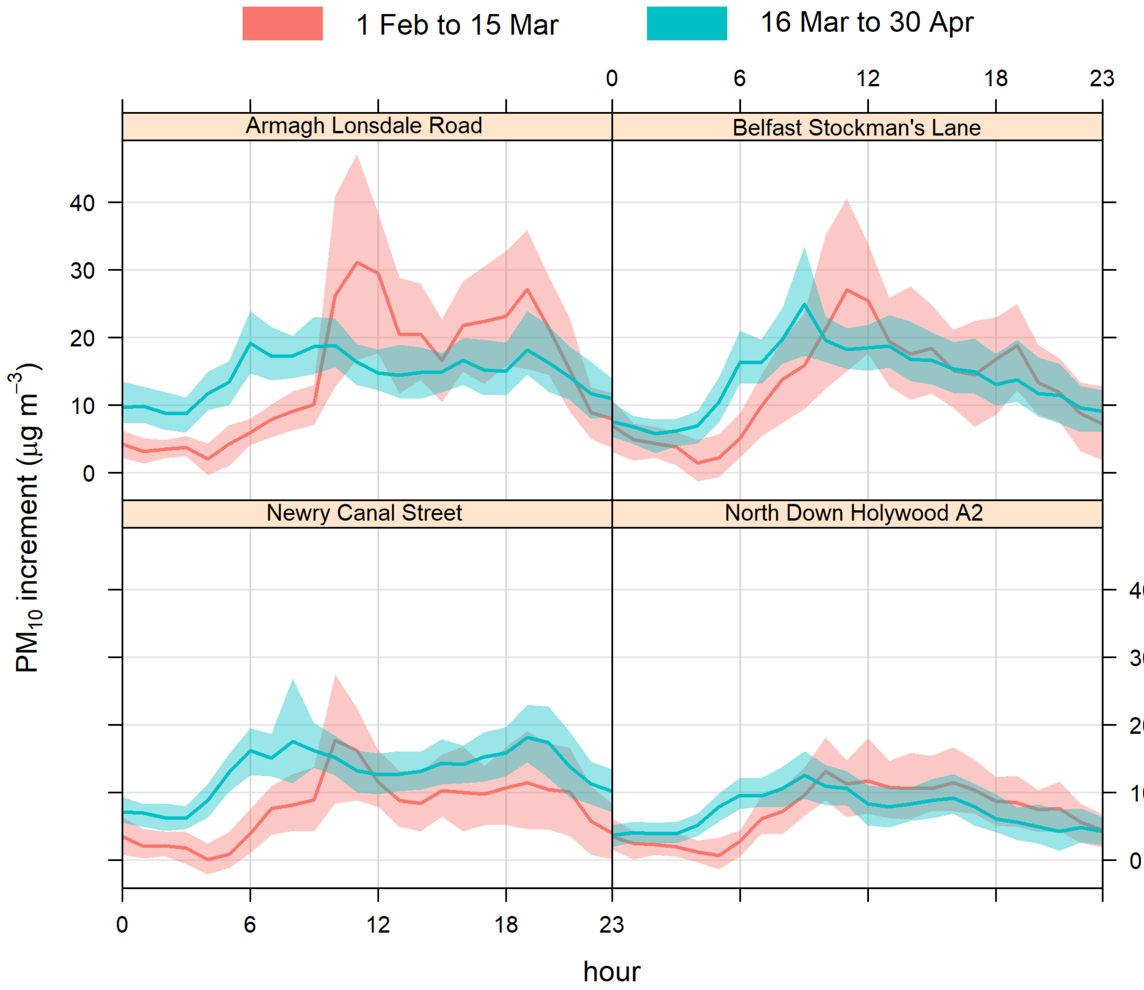


Figure 7-4 Average weekday diurnal variability in the urban PM_{10} increment at urban roadside monitoring sites across Northern Ireland, for the periods 1st February to 15th March 2020, and 16th March to 30th April 2020. (Times GMT).



An analysis of the hourly variation in PM_{10} was also performed for urban background locations. Urban background sites are situated away from local sources, such that they represent the concentration of pollutants over an urban wide area. Following the same method applied to the roadside locations, the background concentrations from the Lough Navar rural site were first subtracted from the urban background measurements to determine the urban increment in PM_{10}.

Figure 7-5 shows the average hourly variation in PM_{10} increment for April to June from 2017 to 2020 for the four urban background monitoring sites. Derry Rosemount is the only site that indicates an obvious difference in the PM_{10} for 2020, with higher mean PM_{10} concentrations throughout the day, when compared to previous years.

The average diurnal variation in the urban background PM_{10} for the periods before and after social distancing was implemented at each urban background site, are shown in Figure 7-6. The hourly variations show that PM_{10} concentrations typically peak in the late evening hours which may be due to domestic fuel burning for heating. During lockdown, many people were at home who would have usually been at work, so it may be expected that PM_{10} from domestic burning would increase. However, the diurnal cycles do not show evidence of the PM_{10} increasing, and Ballymena Ballykeel and Strabane Springhill Park indicate a decrease in PM_{10} in the evenings compared to before lockdown. It should also be borne in mind that lockdown coincided with the beginning of spring, when warmer weather would reduce the need for home heating.

Figure 7-5 Average diurnal variability in the urban background PM_{10} increment at four monitoring sites across Northern Ireland, for April, May, and June from 2017 to 2020.

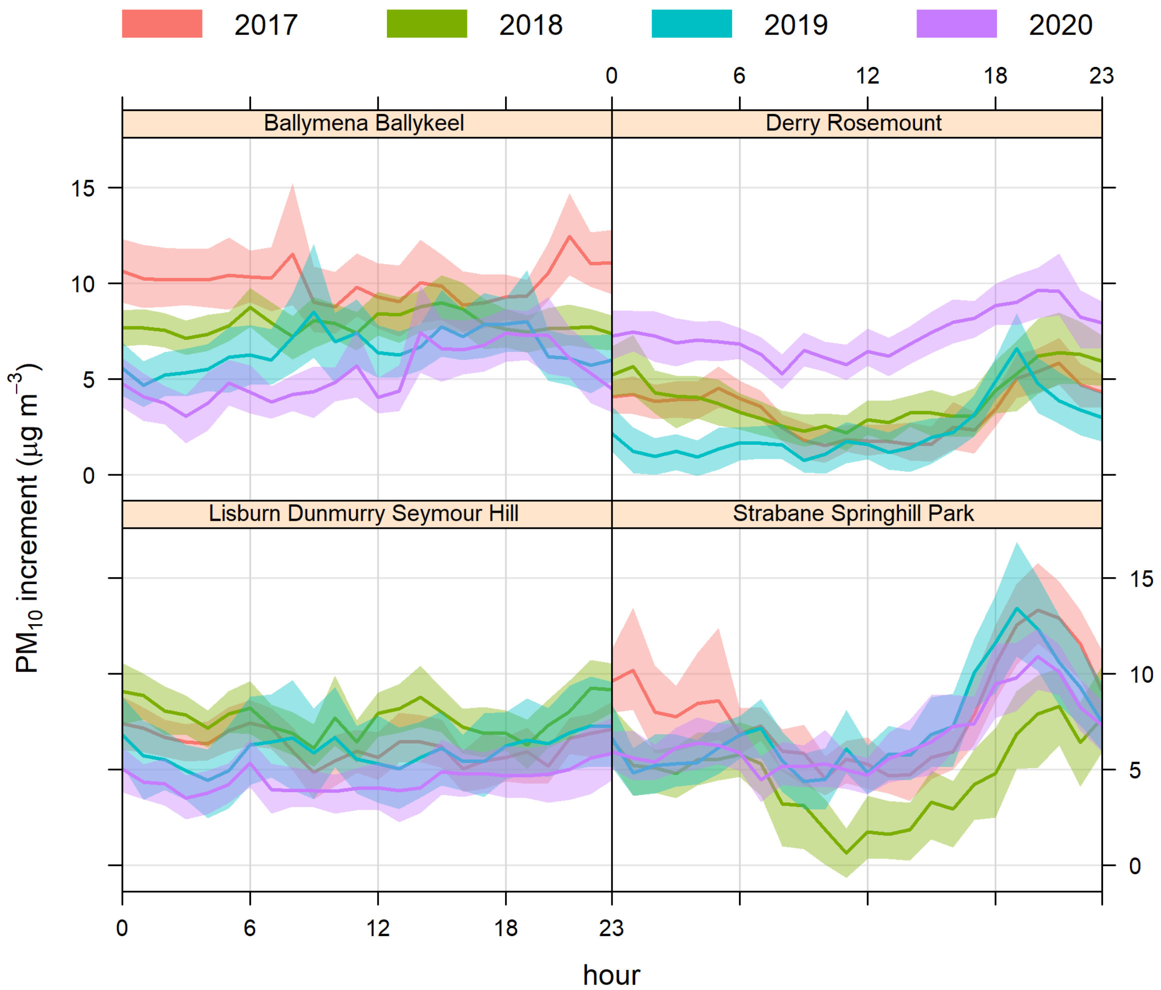
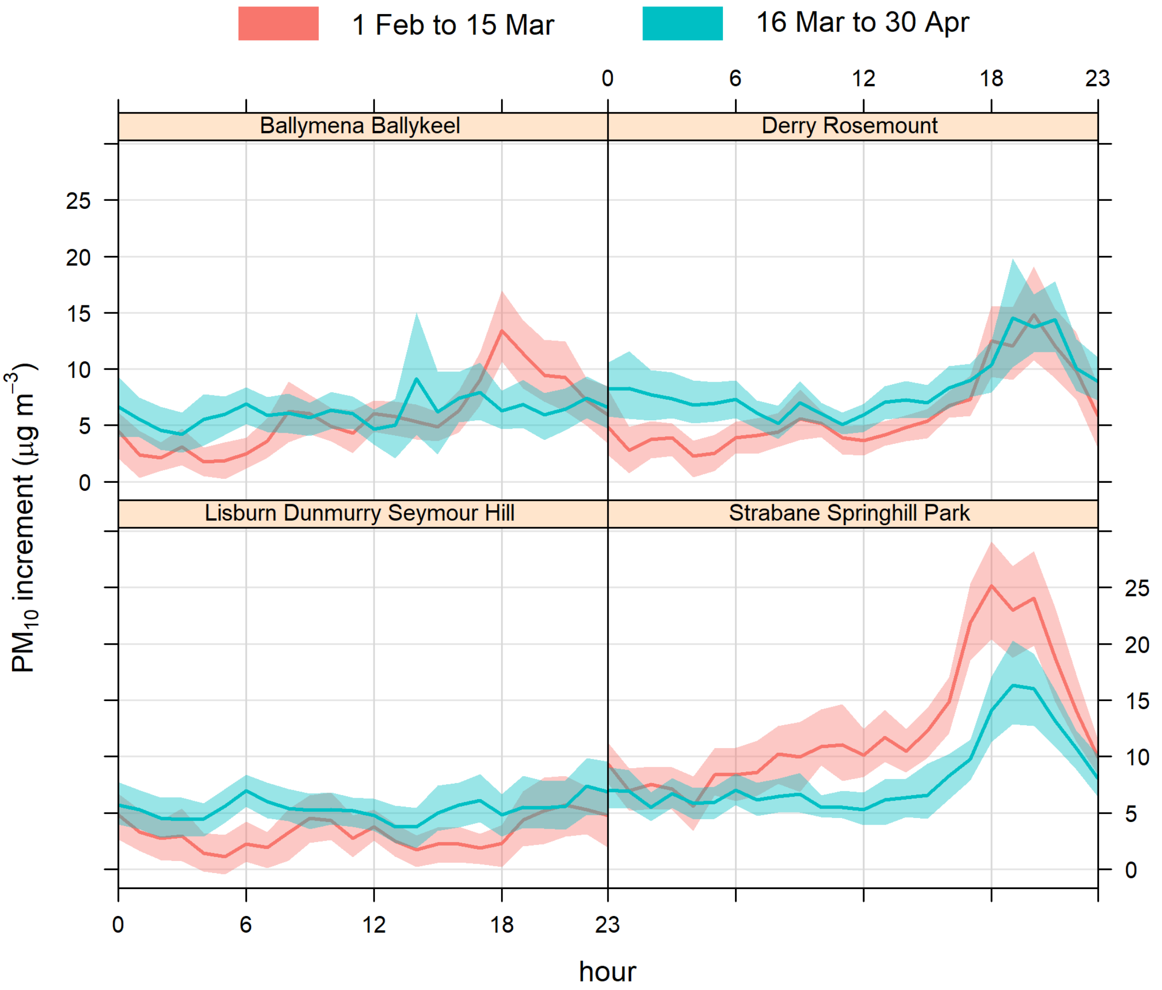


Figure 7-6 Average diurnal variability in the urban background PM_{10} increment at four monitoring sites across Northern Ireland, for the periods 1st February to 15th March 2020, and 16th March to 30th April 2020.



8 Health Context

The Department of Health has been recording a range of Covid-19 related statistics for Northern Ireland, and making them available to the public on a daily basis via their online Daily Dashboard (Department of Health, 2020). The Northern Ireland Statistical Research Agency (NISRA) also publish and regularly update Covid-19 statistics online (Northern Ireland Statistics and Research Agency (NISRA), 2020).

The focus of this report is on the impact of the Covid-19 lockdown on air quality: it does not attempt to quantify the impacts that air pollution episodes may have had on the number of Covid-19 infections, hospital admissions or deaths. Such an analysis would require detailed analysis by epidemiological and medical specialists, including consideration of possible time-lag between dates on which elevated pollution concentrations occurred, and health impacts. This is beyond the scope of the report and outside the area of expertise of the authors.

However, to provide context, we here include dates on which pollutant concentrations reached the 'Moderate' band anywhere in Northern Ireland, according to the Daily Air Quality Index:

- 5th Mar, Belfast Stockman's Lane only (PM_{10})
- 10th Apr (PM_{10})
- 24th -25th Apr (O_3)

- 6th – 7th May (O_3)
- 28th – 31st May (O_3).

For information on how air pollution might have influenced Covid-19 cases and health outcomes, the reader is referred to a study by the Office for National Statistics (ONS) on Covid-19 susceptibility, which investigated whether previous long-term exposure to air pollution had an impact on Covid-19 related deaths. The ONS study, available online, found that Covid deaths were more common in highly polluted areas, but that this correlation between pollution and mortality decreased as lockdown was introduced, and levelled off in early May (Office for National Statistics, 2020). The ONS concluded that the observed correlation with pollution in the early stages of the pandemic was because of the large outbreak in London, before the virus began to spread outside the capital.

The ONS report cited several international studies, all of which had reported positive associations between air pollution and Covid-19 mortality.

Northern Ireland's first Air Quality App was launched in May 2020. The App gives the public up to date information on average air pollution levels across Northern Ireland and a five-day air quality forecast. Users can set up a push notification to alert them to when levels of elevated pollutants are detected or forecast. (Further information can be found at https://www.airqualityni.co.uk/stay-informed).

9 Conclusions

9.1 Conclusions Relating to Emission Sources

- Electricity generation is a significant source of NO_X and SO_2 in Northern Ireland. Data from SONI Ltd indicated that there were substantial reductions in electricity demand in April and May 2020. The reductions in demand specifically due to lockdown (i.e. taking into account year-on-year decrease observed in recent years) have been estimated as approximately 12% in April 2020 and 8% in May 2020, with demand returning to normal in June 2020.
- However, these decreases in demand will not necessarily have resulted in NO_X and SO_2 emissions from power generation decreasing by the same percentages. The amount of energy generated from coal and gas over the lockdown period remained within the usual range, with the decrease in demand apparently being managed by reductions in generation from other sources such as wind power. (This is possibly because such sources are more able to respond to short-term fluctuations). It is therefore estimated that any reductions in emissions of NO_X and SO_2 from energy generation in Northern Ireland are likely to have been small, probably less than 1% of Northern Ireland's total emissions.
- Traffic count data from 14 locations showed that total traffic counts began to fall sharply around the point at which social distancing began (16th March), typically dropping to around one third of usual levels in early April.
- Although traffic levels quickly began to rise again, and did so steadily through May and June, they had still not returned to pre-lockdown levels by the beginning of July. There is therefore some evidence of longer-term reductions in traffic flow.
- Road traffic accounts for an estimated 30% of Northern Ireland's total NO_X emissions, therefore the observed reduction in road traffic is estimated to have caused a short-term reduction of approximately 20% of Northern Ireland's total NO_X emissions during the early weeks of the lockdown period. (Please note, however, that reductions in measured ambient concentration may be greater or less than this, depending on the relative importance of traffic emissions at any given monitoring site).
- There was a very substantial drop in air traffic flying to and from Belfast's two airports, with passenger flights almost ceasing entirely. Total aircraft movements over the period March to May 2020 period, at Belfast International Airport and Belfast City Airport appear to have been reduced to 27% of the usual numbers.
- The dramatic reduction in air traffic is expected to also have reduced road traffic to and from the airports (for example the observed reduction in traffic on the A2 near Belfast City Airport.

- From the beginning of lockdown on 23rd March, to 11th May, Translink rail services operated a much reduced 'Sunday +' timetable. During this period there were just 52% of the normal number of services. Thereafter this increased to a 'Saturday +' timetable, of about 88% of the normal number of services.
- The reduction in rail services is also likely to have contributed to the observed fall in road traffic.
- No data are available for shipping: however, it is reasonable to assume a similar reduction to that observed for air travel.
- Information provided by NIEA indicate the lockdown appears to have reduced emissions from NIEA-regulated industrial processes. Emissions from the cement, glass and non-ferrous metal sectors had been lower than usual during the six-week period from mid-March to the end of May, as some plant had been temporarily shut down. Most had re-started by early June, though at reduced capacity.
- NIEA were unaware of any significant increase or decrease in emissions from the agriculture sector. Emissions from this sector are largely dependent on the life cycles of crops and livestock: it is therefore assumed that these emissions have not been substantially affected by the lockdown. These include emissions of ammonia, which is a significant precursor involved in the formation of particulate pollution.
- Data from NIEA showed an increase in reported incidents of waste crime, which include fly-tipping and unauthorised waste burning, compared to previous recent years. Non-domestic waste burning incidents in particular showed a rise during the lockdown period.
- Data from Northern Ireland's District Councils showed that some (though not all) had experienced an increase in complaints about nuisance burning on domestic premises during January to June 2020, compared to the same period in 2018 and 2019. The majority of the complaints related to outdoor burning, particularly of waste or rubbish, rather than smoke from chimneys or appliances.
- On the evening of 24th May, there was a large accidental fire at an industrial premises in the Belfast docks area. However, it appears that the wind direction was such that the smoke was blown out to sea rather than over the city: no increases in particulate pollution were measured at Belfast's monitoring stations.
- Six rural wildfires occurred in Northern Ireland during April and May. These do not appear to have resulted in measurable increases in particulate pollution at any monitoring stations.

9.2 Conclusions Relating to Meteorology, Wind and Air Mass Back Trajectories

- There was a marked difference in prevailing meteorology, between the period before social distancing began (1st Jan – 15th Mar), and the subsequent 'lockdown' period to the end of May. Pre-lockdown, the wind direction was predominately from the south-west with a mean wind speed of 6.2 ms^{-1}. This would have brought relatively clean air from the Atlantic to Northern Ireland. Subsequently, over the period 16th Mar – 31st May the mean wind speed dropped to 4.3 ms^{-1} and the wind direction was more variable. These conditions were potentially less conducive to good air quality. These seasonal variations may have influenced Northern Ireland's air quality during the relevant periods.
- There were several periods of elevated pollution before and during the lockdown period, when levels of either PM_{10} or O_3 reached the 'Moderate' air quality index band:
    - 5th Mar, Belfast Stockman's Lane only (PM_{10})
    - 10th Apr (PM_{10})
    - 24th -25th Apr (O_3)
    - 6th – 7th May (O_3)
    - 28th – 31st May (O_3).
- The ozone episodes in April, May and June were wider regional events, affecting large parts of England and Wales also.

9.3 Conclusions of Analysis of Changes in Ambient Concentrations

- The cumulative sum (cusum) analysis revealed there were substantial reductions in ambient NO_X and NO_2 concentrations as a result of the lockdown restrictions.
- On average, over the lockdown period until the end of June, NO_X concentrations were 52% lower than the 'business as usual' (BAU) scenario, corresponding to an absolute average reduction of 37 µg m^{-3}. Both roadside and urban background monitoring sites measured clear decreases in NO_X.
- On average, over the period from the beginning of lockdown to the end of June, NO_2 concentrations were 44% lower than BAU. This corresponds to an absolute average reduction of 13 µg m^{-3}.
- In particular, the four monitoring sites which had reported annual mean NO_2 concentrations above the Air Quality Strategy objective of 40 µg m^{-3} in 2019 (Belfast Stockman's Lane, Downpatrick Roadside, Limavady Dungiven and Newry Canal Street) had mean concentrations less than 30 µg m^{-3} during the lockdown period.
- The analysis of PM_{10} concentrations was challenging, as PM_{10} concentrations tend to be dominated by regional background levels rather than local primary emissions. This study focussed on changes to the 'urban increment' PM_{10}, i.e. the amount by which the PM_{10} at each urban site differed from the rural background concentration measured at Lough Navar. There was considerable variation in urban increment from site to site, with some sites showing an increase and others showing a decrease, compared to BAU. Overall, there was no clear change in the PM_{10} urban concentration increment. Conclusions on changes in PM_{10} should be considered as subject to greater uncertainty, compared with the changes seen for other pollutants.
- It was not possible to carry out a similar analysis for $PM_{2.5}$: the process requires the calculation of the 'urban increment', which necessitates rural background data. Rural measurement of $PM_{2.5}$ in Northern Ireland began only relatively recently, making it difficult to model the urban increment robustly, for $PM_{2.5}$.
- Black carbon is measured at four sites: two of these had large amounts of missing data. However the site in Strabane showed strong evidence of a decrease. Weaker evidence of a decrease was seen at the Kilmakee site.
- Ozone increased over the period of interest. This would be expected due to the typical seasonal pattern for O_3, which exhibits higher concentrations in summer months. However, the two urban sites showed substantial increases compared with BAU (23% at Belfast Centre and 20% at Derry Rosemount), while the rural site Lough Navar showed a much smaller increase of just 3%. The fact that the urban sites exhibited a greater increase compared with BAU than the rural site did, suggests another factor was involved. It is possible that urban O_3 concentrations were higher than they otherwise would have been, due to lower levels of NO (which would normally react with O_3 and remove it from the air).
- Despite the above evidence that reduced NO concentrations may have exacerbated urban ozone levels, it would be a mistake to conclude that NO_X emissions are beneficial. Oxides of nitrogen are involved in the formation of ozone as well as its removal, and have health impacts of their own. Besides, other harmful pollutants such as particulate matter and SO_2 are often emitted along with NO_X, from the same sources.
- SO_2 showed varying patterns from site to site, with some having increased and some decreased: however, it should be noted that the concentrations are low compared to the detection limit of the method, which presents challenges for measurement.

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