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Effects of Covid-19 Restrictions on Air Quality in Northern Ireland: Summary Report

Report for DAERA

Report for DAERA – 1627370 Variation 4

ED12568117-001 | Issue 2 | Date 25/11/2021

Ricardo

Customer:

Department of Agriculture, Environment and Rural Affairs (DAERA)

Customer reference:

1627370 variation 4

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10th May 2021

Ref: ED12568016-001

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1 Introduction

In February 2020, the Covid-19 coronavirus pandemic began affecting Northern Ireland. To protect the population, a series of restrictions were imposed. These began with social distancing advice on 16th March, followed by lockdown which began on 23rd March. Under lockdown, people were told to work from home where possible, go out only for essential purposes, and to travel only if absolutely necessary. The lockdown restrictions remained in place throughout April and May 2020, with some being gradually eased in the following months.

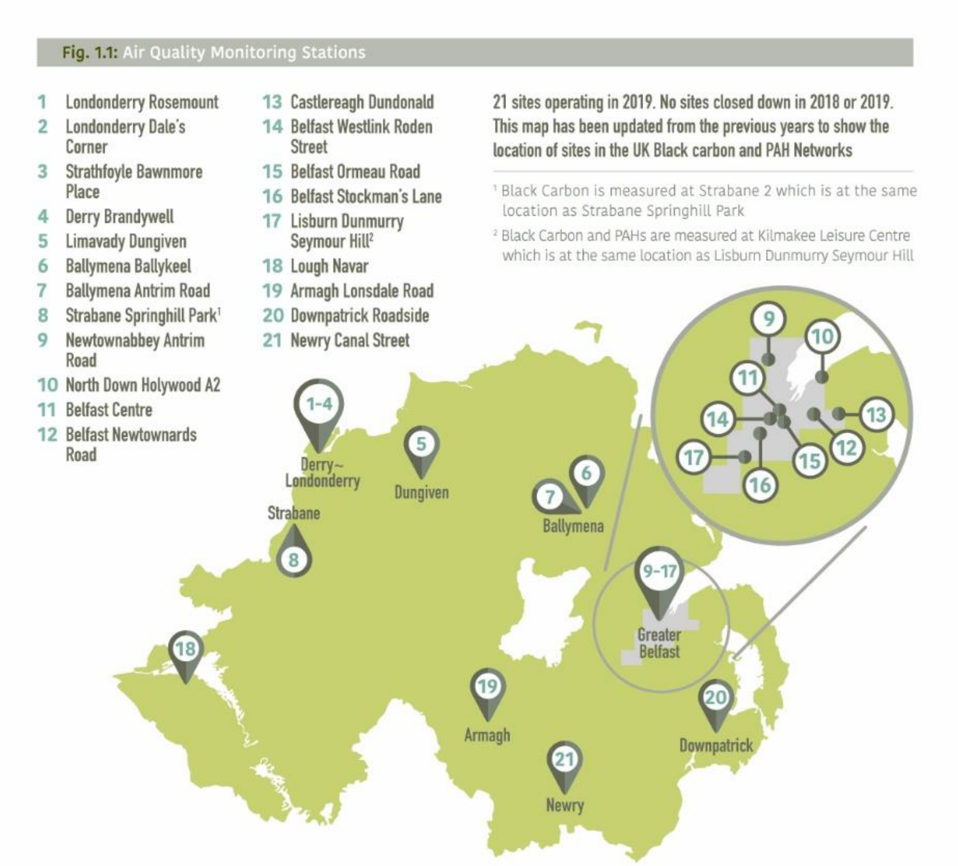
The lockdown restricted many activities including travel, business and industry. Northern Ireland's Department of Agriculture, Environment and Rural Affairs (DAERA) wanted to find out whether the lockdown had any effect on air pollution, and asked Ricardo Energy and Environment to carry out an investigation. The full report is available from the Northern Ireland Air website at https://www.airqualityni.co.uk/ : this report provides a short summary of this investigation and its findings.

The first step was to investigate whether the lockdown restrictions caused changes in air pollutant emissions across Northern Ireland. To assess this, we used data including:

- Transport: road transport (traffic count data), air, rail and shipping data (where available)
- Power generation
- Industrial activity
- Agriculture
- Complaints to District Councils of nuisance bonfires and domestic burning

Then, we examined how Northern Ireland's air quality changed as a result of lockdown, using data from Northern Ireland's network of automatic air quality monitoring stations, shown in Figure 1-1.

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



The main pollutants covered in the investigation are described below. For more information on them, please see the '*Pollutants*' page of the Northern Ireland Air Quality website, at https://www.airqualityni.co.uk/air-quality/pollutants.

Oxides of Nitrogen: pollutant gases formed in most processes where a fuel is burned, such as vehicle engines, domestic heating and power generation. These emit a mixture of oxides of nitrogen, primarily nitric oxide (NO) and nitrogen dioxide (NO_2), together referred to as NO_X.

Ozone (O_3) is found naturally in our atmosphere. High up in the atmosphere the *ozone layer* protects life on earth from the sun's harmful ultraviolet rays. However, at ground level, it is an air pollutant. Ozone is not emitted directly from any man-made source in any significant quantities. Instead, it is mostly formed, in the lower atmosphere, by chemical reactions between other groups of so-called 'precursor' pollutants – Volatile Organic Compounds (VOCs) and NO_X. These reactions are started 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). This means ground-level O_3 pollution is usually worse in the summer, especially during warm, sunny weather.

Ozone is considered a 'transboundary' pollutant, as ozone measured at a particular location may have arisen from VOC and NOx emissions many hundreds or even thousands of miles away. Highest concentrations of ozone usually occur some distance downwind of the original sources of precursor emissions – often in rural areas.

O_3 can be removed from the air via reaction with nitric oxide (NO). This 'scavenging' process can actually lower O_3 concentrations in urban areas and is another reason why O_3 concentrations are often highest in rural areas. (However, this does not mean that NO_X emissions are a good thing).

Particulate Matter (PM) comprises a wide range of materials, both natural (dusts, sea salt, volcanic emissions and biological particles) and human-made (burning of wood and coal, agriculture, industrial processes, road dust and dust from tyre and brake wear, and construction work). There are also particles that are not emitted from any source but formed by chemical reactions between other air pollutants – known as secondary particulate matter.

These airborne particles are measured in size fractions according to their effective size. Most air quality monitoring measures **PM_{10}** (particles with an effective size of 10 micrometres or less[1]) or **$PM_{2.5}$** (particles with an effective size of 2.5 micrometres or less). A micrometre, or micron, is one-thousandth of a millimetre. PM_{10} particles 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 and may carry surface-absorbed toxic, or carcinogenic, compounds into the body.

Black carbon - 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 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. It is measured separately from PM_{10} and $PM_{2.5}$, using a different measurement method.

The study also looked at carbon monoxide and sulphur dioxide, although these are monitored at fewer sites so there is less data available. For information on these, please see the main report at https://www.airqualityni.co.uk/ .

[1] The 'effective size' referred to here is actually the *median aerodynamic diameter*.

2 Methodology and Approach

This section describes how the study was carried out. For a full explanation please see the main report and references (Carslaw, D.C. & Taylor, P.J., 2009), (Grange, S.K. & Carslaw, D.C., 2019), (Grange, S.K. et al., 2018). Sources of information were as follows:

- Pollutant emission data – came from the National Atmospheric Emission Inventory (NAEI) website at https://naei.beis.gov.uk/ , and 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)***.*** These data are estimates.
- Air quality monitoring measurements – came from Northern Ireland's network of 20 automatic monitoring sites shown in Figure 1-1 above. Data from these sites are available from the Northern Ireland Air Quality Website at https://www.airqualityni.co.uk/ (DAERA, 2020).

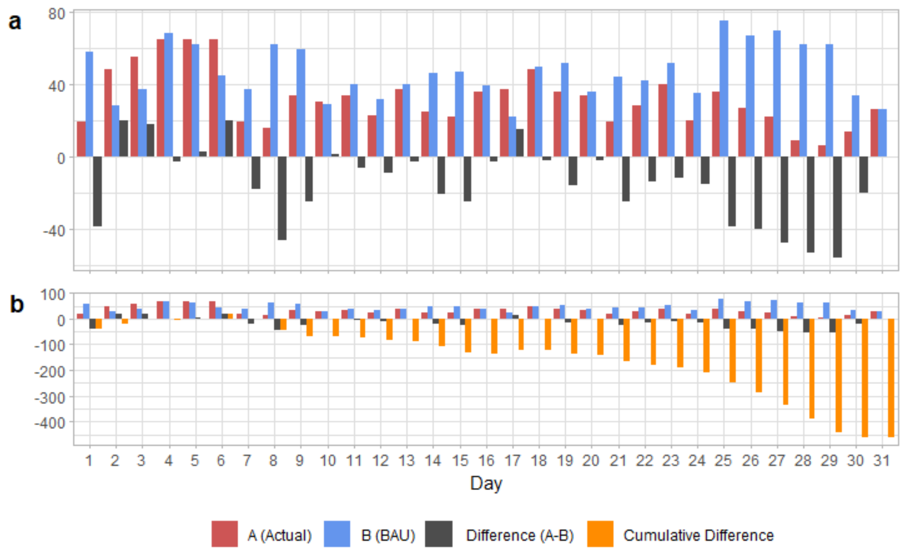
Ricardo used mathematical models to predict what the daily and hourly concentrations of pollutants *would* have been, if 2020 had been an ordinary year with no lockdown. This is referred to as the '***Business As Usual' (BAU)*** scenario. The models used hourly pollution data from Northern Ireland's monitoring stations (Figure 1-1 above), and meteorological data from the Weather Research and Forecasting (WRF) regional scale model. The models were tested by comparing their predictions with real pre-lockdown monitoring data (which had not been used in preparing the model) and found to do a very good job of predicting air quality. The models were then used to predict hourly concentrations from 1st March onwards at each site: the BAU scenario.

The next stage was to compare actual measured concentrations with the modelled BAU and look at the differences. This used a technique called *cumulative sum analysis* **('cusum analysis' for short)**. Cusum analysis works by keeping a cumulative total of differences from the BAU – which should on average be zero if things continue as normal. But if pollution levels start to increase, or decrease at some point in time, the cumulative sum will begin to get larger – or smaller – with time. This is useful in pinpointing when changes began, especially when the changes are difficult to see in the data alone.

Figure 2-1 illustrates how cusum analysis works. The top bar chart shows a series of daily actual measured values (A) in red, and the modelled 'business as usual' values (B) in blue, for one month. Also shown is the difference between actual and BAU, in black.

In the bottom chart, we have added the *cumulative sum* of these differences (that is, cusum for day 1 = day 1's difference: for day 2 it is day 2's difference plus day 1's difference and so on, until the cusum for the final day is the sum of the differences for all previous days, 1 to 31.) This graph now illustrates much more clearly that there is a point at which the 'actual' value A begins to be lower than the 'BAU' prediction. This point is around day 8 in the illustration.

Figure 2-1 Example of cusum analysis for one month.



3 Review of Emissions

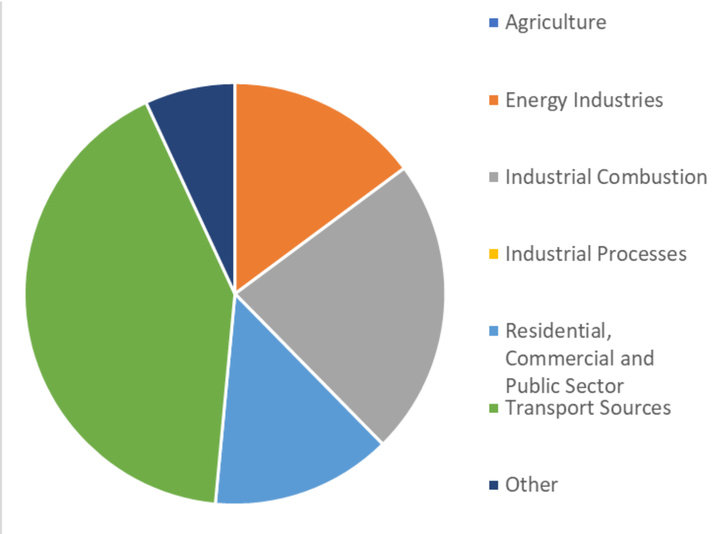
3.1 Overview of Emission Sources in Northern Ireland

In this section we provide 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).

Ammonia (NH_3) is involved in many environmental processes, including the formation of 'secondary' particulate matter (ammonium sulphate and nitrate particles). Almost all of Northern Ireland's ammonia emissions are from agriculture (96%).

Oxides of Nitrogen (NOx): the region's biggest source of NO_X is Transport (42%). Of this 42%, nearly half (46.7%) comes from passenger cars, accounting for 19.6% of the region's total NOx emissions. Other 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). Pollution from road transport is believed to be particularly significant for health impacts: unlike emissions from most industrial sources, vehicle emissions are produced near ground level, often in urban areas where people are present (DAERA, 2015).

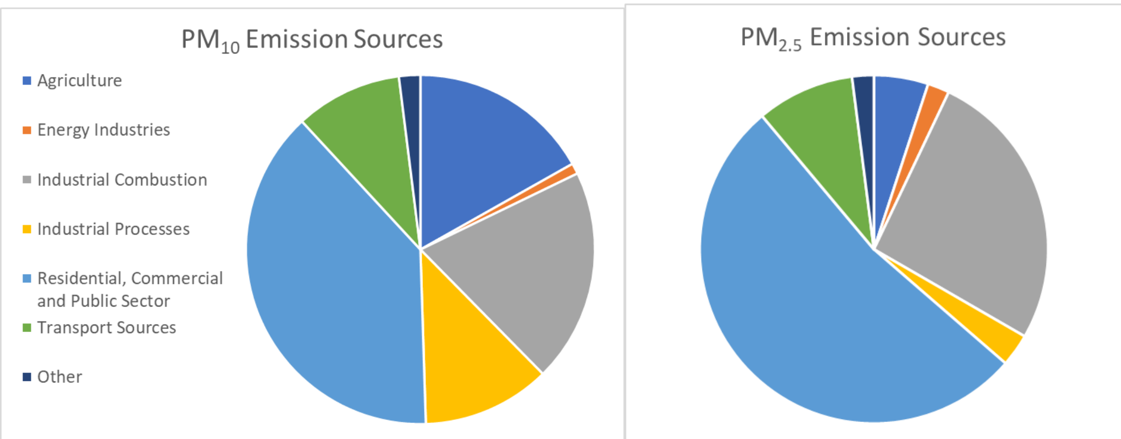
Figure 3-1 NOx Emission Sources



Ozone (O_3): as explained in Section 1, most ground-level ozone is not emitted from any source, but formed in the atmosphere from reactions between other pollutants, helped by sunlight and heat.

PM_{10} and $PM_{2.5}$ emissions are primarily from the 'Residential, Commercial and Public Sector' category. Industrial Combustion and Transport are also important sources, and 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. Some particulate matter also comes from 'secondary' particulate matter such as particulate sulphate and nitrates, and from natural sources such as suspended soil, dust and sea salt.

Figure 3-2 PM Emission Sources



3.2 Assessment of Changes in Emissions

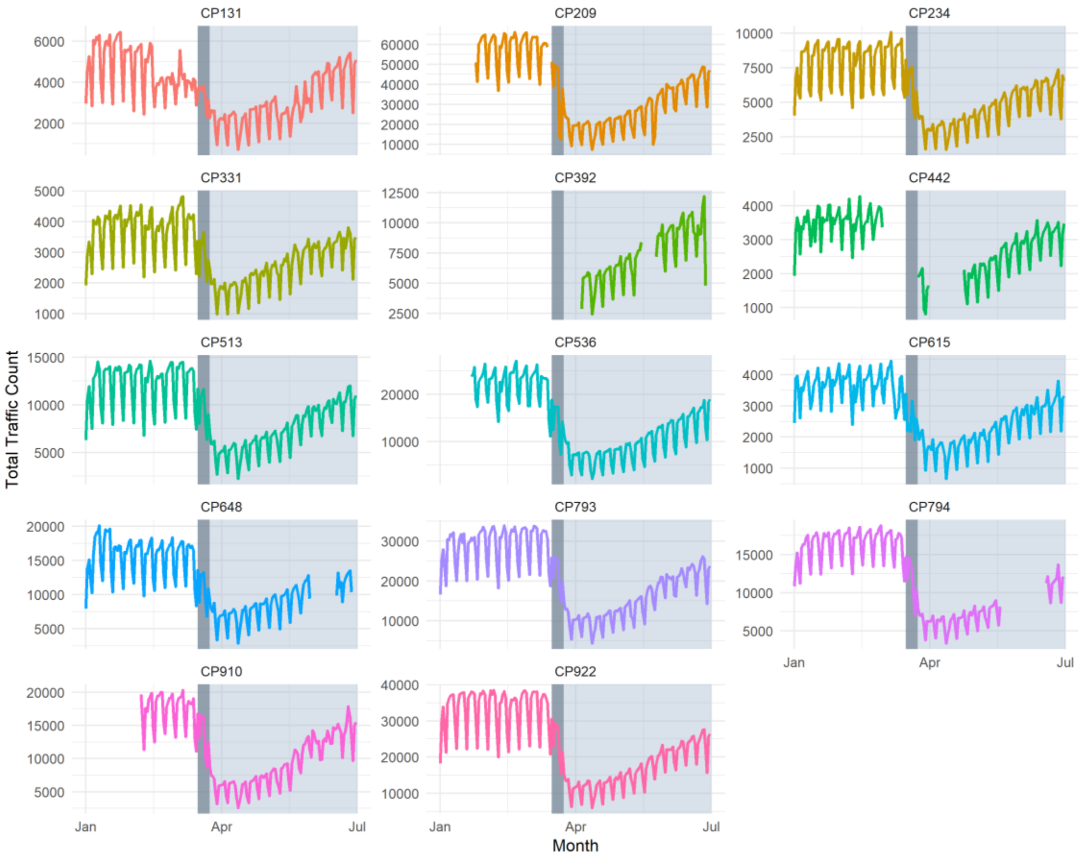
Power Generation and Consumption: power generation in Northern Ireland accounts for 15% of the region's NO_X emissions. However, this sector only accounts for 1% of primary PM_{10} emissions and 2% of primary $PM_{2.5}$ emissions. The lockdown restrictions appeared to have caused a drop of approximately 12% in energy generation in April 2020 and approximately 8% in May 2020, with a return to normal in June 2020. However, the amount of energy produced by coal, oil and gas were not unusually low during the lockdown. Therefore, it is estimated that any reduction in pollutant emissions during this period are likely to have been small: probably less than 1% in the case of NO_X.

Domestic fuel burning: During the early part of the lockdown when the weather was cold and more people stayed at home, domestic fuel burning may have increased. However, any increase in domestic fuel burning would likely have been offset by a decrease in fuel use at shops, schools, and businesses which were closed. Domestic fuel burning is not monitored or measured therefore there is insufficient information to quantify this.

Road Transport: Figure 3-3 shows the **daily total vehicle counts** at 14 traffic count points across Northern Ireland from 1st Jan 2020 – 30th Jun 2020, provided by the Department for Infrastructure. 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).

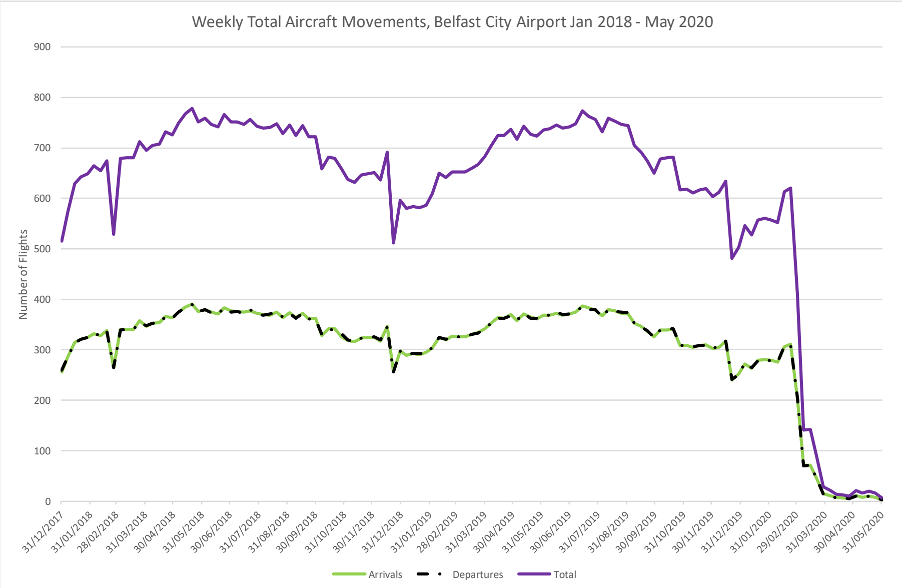
These graphs show there was a sharp decrease in road traffic around the point at which social distancing began, dropping to around one third of usual levels in early April. Traffic then gradually increased, however, even by the beginning of July, traffic counts had not returned to their pre-lockdown levels. Road traffic is estimated to account for 30% of Northern Ireland's total NO_X emissions, therefore, the reduction in traffic during the first few weeks of lockdown is estimated to have resulted in a short-term reduction of 20% in the region's emitted NO_X. Ambient concentrations would not necessarily be expected to reduce by the same amount, however, as non-traffic sources may also contribute.

Figure 3-3 Daily Total Vehicle Counts



Air Transport: The impact of Covid-19 on the air transport industry have been well publicised in the media. Figure 3-4 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. Between 1st Mar and 24th May 2020 aircraft traffic reduced to just 10% of the usual traffic. A similar pattern was seen at Belfast International Airport. The reduction in air traffic is expected to also have reduced road traffic to and from the airports. However, it was not possible to link the reduction in flights to changes in pollution levels, as there are no monitoring stations close to the airport and also because it is not possible to distinguish between aircraft emissions and those from other sources.

Figure 3-4 Weekly Flights, Belfast City Airport Jan 2018 - May 2020



Industrial Activity: The Northern Ireland Environment Agency (NIEA) regulates 'Part A' industrial installations in Northern Ireland. Based on information provided by NIEA to DAERA, the lockdown appears to have reduced emissions from NIEA-regulated industrial processes.

Agriculture: NIEA also regulates the FDM (Food Drink and Milk) and SA (Slaughtering and Animal By-product) sectors. Emissions from the agriculture sector are largely dependent on the life cycles of the animals and crops. We therefore assume these to have been relatively unaffected the lockdown.

Non-Domestic Waste Burning: NIEA investigates reported incidents of waste crime, which include fly-tipping and unauthorised waste burning. The study found evidence of an increase in 2020, compared to the same period in 2019 and 2018, during April and into May. However, it was not possible to quantitatively link this to any specific changes in pollutant concentrations.

Domestic waste burning: Northern Ireland's District Councils keep records of complaints about smoke, odour and other nuisance caused by domestic burning. Some Districts reported clear evidence of increased incidence of nuisance complaints relating to domestic burning, compared to the same period in previous years.

4 Effects of Meteorology

Meteorology (weather conditions) can have a large impact on air quality. For example:

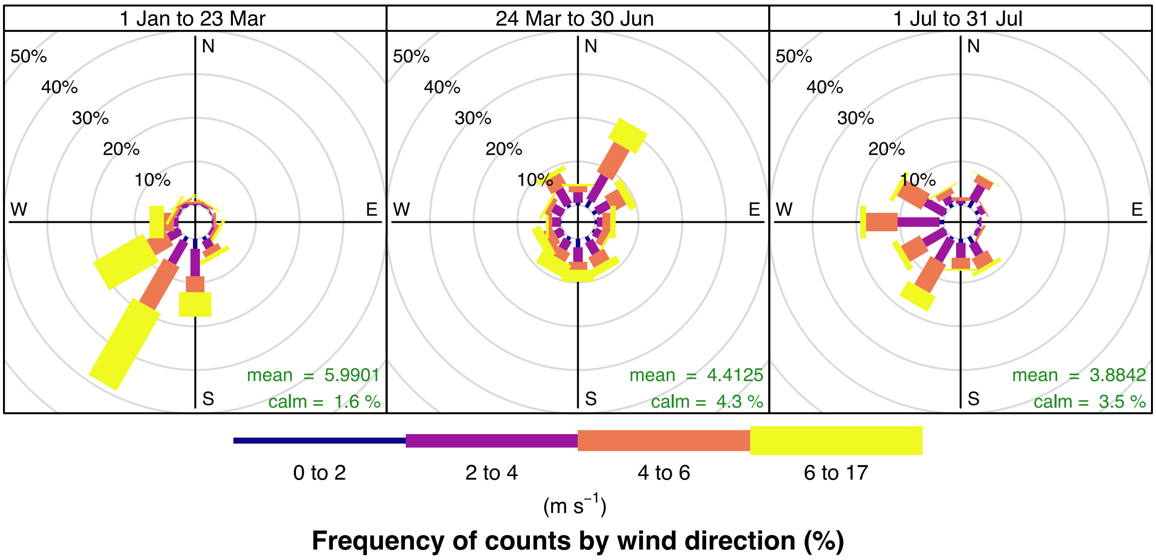
- On cold, still days, pollutants from local sources are not dispersed, and can build up to high levels.
- Hot, sunny days (especially with little wind) increase ozone formation.
- Higher wind speeds tend to disperse locally-emitted pollutants while calm, still weather can allow them to build up.

- Variations in direction can also influence pollutant levels through long-range transport. Wind direction is important: in Northern Ireland, westerly winds typically bring cleaner air from over the Atlantic Ocean, while easterly winds often bring more polluted air from mainland Europe.
- 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 $PM_{2.5}$.

Therefore, when investigating changes in pollutant concentrations, it is important to consider the weather conditions at the time, and the effect these might have had on air quality. For this reason, sophisticated statistical models are needed to determine changes in concentrations without the confounding effect of the weather.

One of the striking aspects of the weather in 2020 was 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 4-1, which will typically have brought relatively clean air to Northern Ireland. Over this period the mean wind speed was 6.0 ms^{-1}. 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, with a mix of wind directions including some north easterly winds. 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.

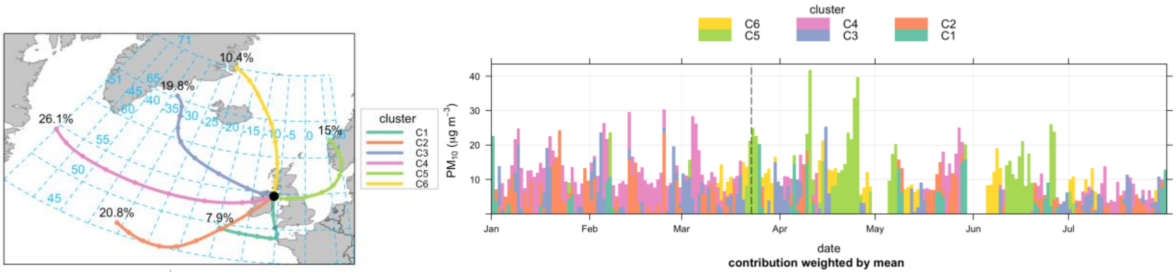
Figure 4-1 Wind rose for Belfast City Airport for 1st January 2020 to 31st July 2020, before, during and after main lockdown period.2020.



So, there was a significant change in weather conditions and wind direction around the time of the onset of lockdown. (It is important to note, this was not caused by the lockdown, but coincided with it).

We also looked into the origin of air masses at different times using "back trajectory" analysis. This type of analysis uses a model to estimate where a parcel of air came from and how it travelled, before arriving at a specific location. The origin of air masses can have an important effect on the concentrations of many pollutants and especially PM. We performed the back trajectory analysis for air masses arriving at the Belfast Centre site and grouped those from similar origins together. The six groups (clusters) are shown on the left in Figure 4-2. The clusters are then linked with PM_{10} concentrations at the Belfast Centre site to explore the relationship between air mass origin and concentration, as shown on the right in Figure 4-2.

Figure 4-2 The map on the left shows the cluster analysis of air mass origins from January to July 2020. The numbers show the percent of time the air was from each cluster. On the right, the graph shows the 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.



Analysis of the air masses arriving at the Belfast Centre site showed that pre-lockdown, weather conditions were such that air masses 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. By contrast, during the lockdown period, particularly in April and early May, the weather changed and 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. 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 $\mu g\ m^{-3}$.

As highlighted above, certain meteorological conditions are conducive to elevated concentrations of pollutants in Northern Ireland. Here, we look more closely at periods of high pollution prior to and during the lockdown period.

During the period January to May 2020 there were two days when PM_{10} reached the ‘Moderate’ band (as defined by the UK Daily Air Quality Index) in Northern Ireland. The first of these occurred on 5th March 2020 before social distancing or lockdown began. Belfast Stockman’s Lane reported a 24-hour mean PM_{10} of 51 $\mu g\ m^{-3}$, 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.

The second episode was on 10th April 2020 – this was a wider pollution episode, with Wales and the majority of England also affected. 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.

There were also three periods when ozone concentrations in Northern Ireland reached ‘Moderate’ levels: 24th – 25th April, 6th – 7th May, and 28th – 31st May. 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.

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.

The difficulty with the analysis of PM and O_3 is that it is not easy to determine a ‘Covid-19’ effect as both O_3 and PM concentrations are dominated by regional and even global processes. Only regional scale air quality modelling is likely to provide estimates of any changes due to lockdown.

The findings presented here 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 Analysis of Changes in Pollutant Concentrations

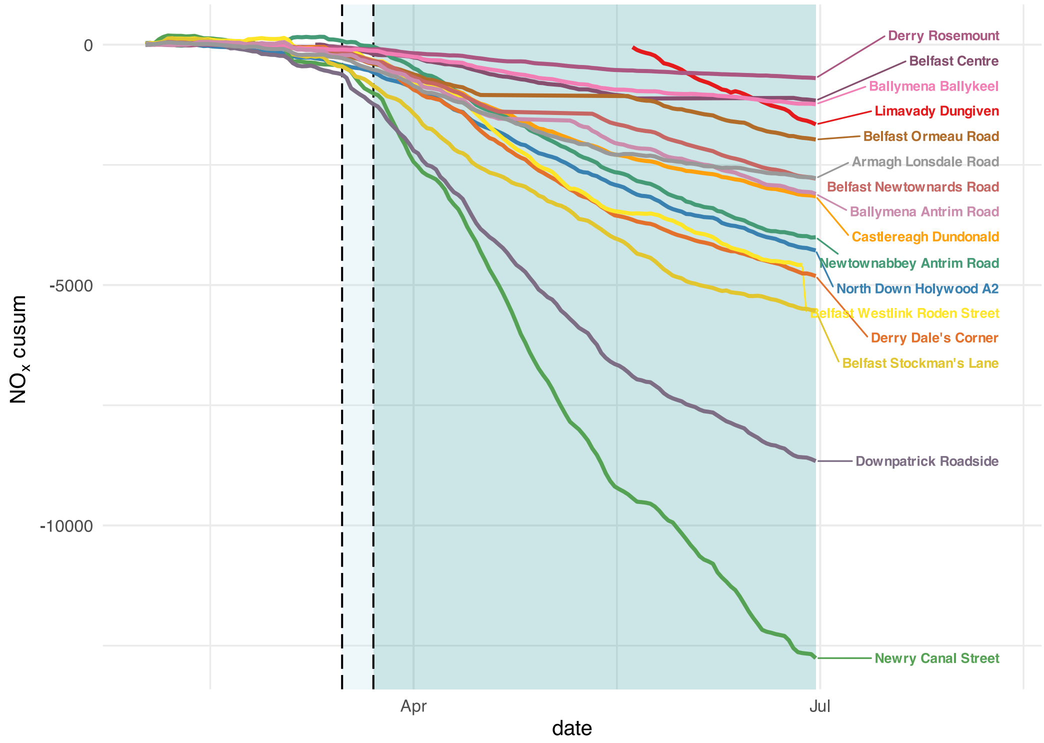
5.1 Analysis of Changes in Total NO_X Concentration

Figure 5-1 shows daily mean concentrations of total NO_X ($NO + NO_2$) at air pollution monitoring sites across Northern Ireland from 1st February to 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 5-1 Daily mean concentrations of NO_X at a range of air pollution monitoring sites across Northern Ireland from 1st February 30th June 2020.

From this plot alone, it is not clear whether concentrations changed when lockdown started. But by plotting the cumulative sum (cusum) of measured minus Business As Usual (BAU) NO_X at the same monitoring sites (Figure 5-2), we can see a clearer indication of the changes. Most of the lines start to slope downwards around the start of lockdown. (Flat sections of line correspond to gaps in the dataset e.g. for Belfast Ormeau Road.) Although the sites show different patterns, all show some decrease in NO_x concentration. Overall, there is clear 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 5-2 The cumulative sum (cusum) of measured minus business as usual NOx concentration at a range of air pollution monitoring sites across Northern Ireland.



The percentage change in concentration relative to BAU for the period 23rd Mar – 30th Jun 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, 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.

5.2 Analysis of Changes in NO_2 Concentration

Nitrogen dioxide (NO_2) is of particular interest as several sites in Northern Ireland have exceeded limit values or objectives for this pollutant in recent years. Four 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 5-3 shows daily mean concentrations of NO_2 at monitoring sites across Northern Ireland from 1st February 30th June 2020. Shading indicates the social distancing and lockdown periods as in Figure 5-1. Figure 5-4 shows the cusum of measured NO_2 minus modelled BAU, at each site.

Figure 5-3 Daily mean concentrations of NO_2 at a range of air pollution monitoring sites across Northern Ireland from 1st February 30th June 2020.

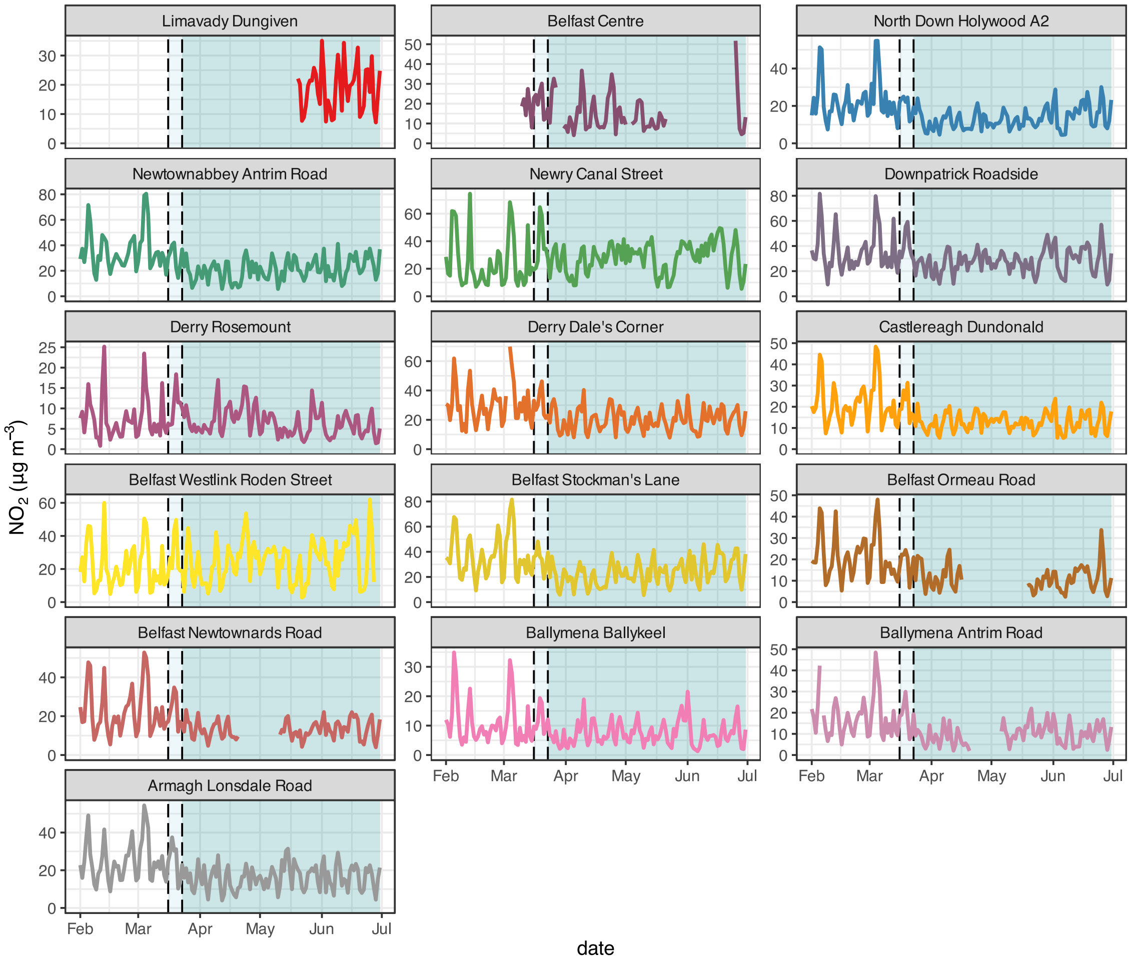
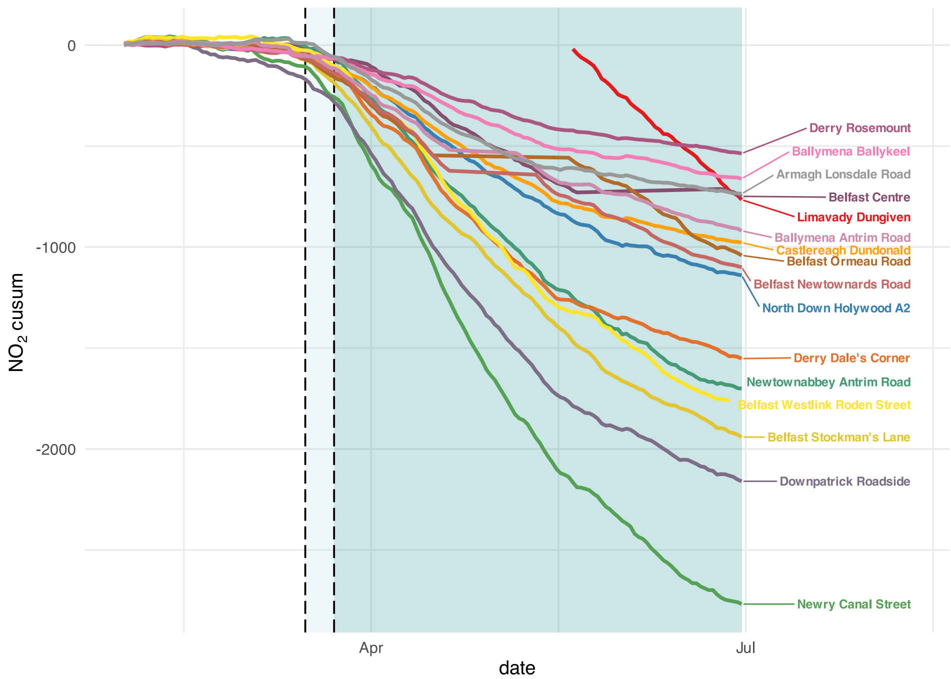


Figure 5-4 The cumulative sum (cusum) of measured minus business as usual NO_2 at a range of air pollution monitoring sites across Northern Ireland.



Averaged across all sites, NO_2 concentrations over the period 23rd March to 30th June were 44% lower than BAU (ranging from 30% to 54% lower), corresponding 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 than 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.

5.3 Analysis of Changes in Ozone Concentration

Ozone is measured at three sites: Lough Navar (remote rural) Belfast Centre (urban centre), Derry Rosemount (urban background). There was no clear change in daily mean O_3 concentrations at the start of lockdown (Figure 5-5). However, the cusum plot (Figure 5-6) shows a much clearer pattern. At rural Lough Navar, there is very little evidence that concentrations changed due to lockdown. By contrast, urban sites Belfast Centre and Derry Rosemount show clear evidence of an *increase* in O_3 concentrations since lockdown.

Belfast Centre and Derry Rosemount showed increases of 23% and 20% respectively, while Lough Navar showed a much smaller increase of just 3%. 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 an increase in O_3. These changes highlight why it would be difficult to conclude that air quality overall has improved, as it depends on the pollutant in question.

Figure 5-5 Daily mean concentrations of O_3 at three air pollution monitoring sites in Northern Ireland from 1st February to 30th June 2020.

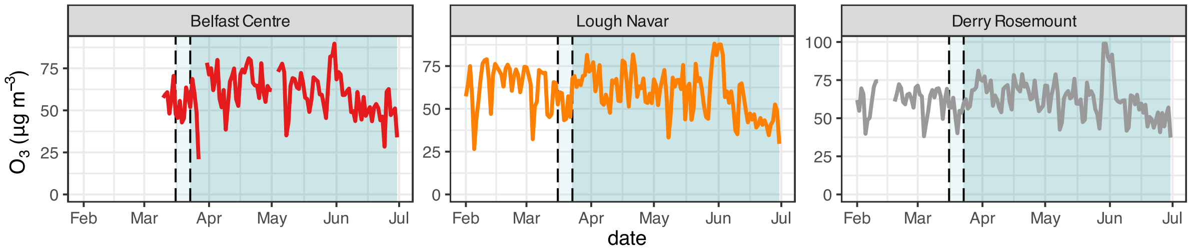
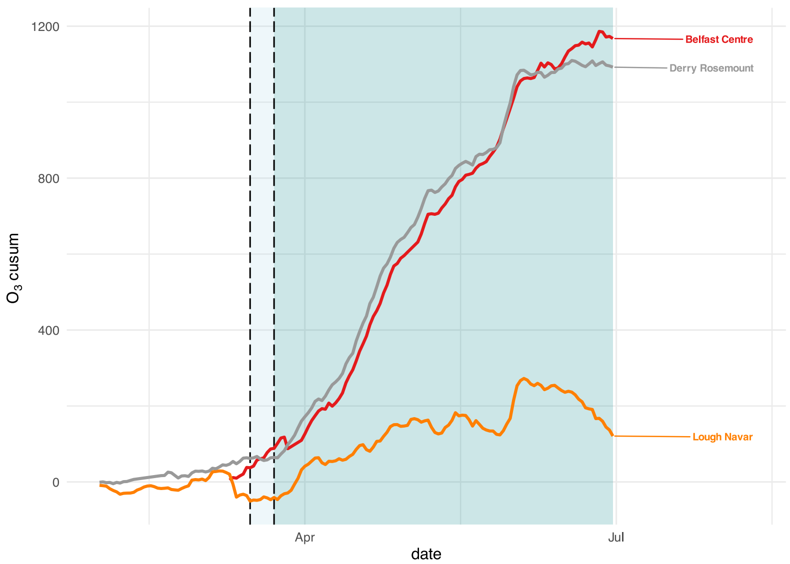


Figure 5-6 The cumulative sum (cusum) of measured minus business as usual O_3 at three pollution monitoring sites across Northern Ireland.



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.

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.

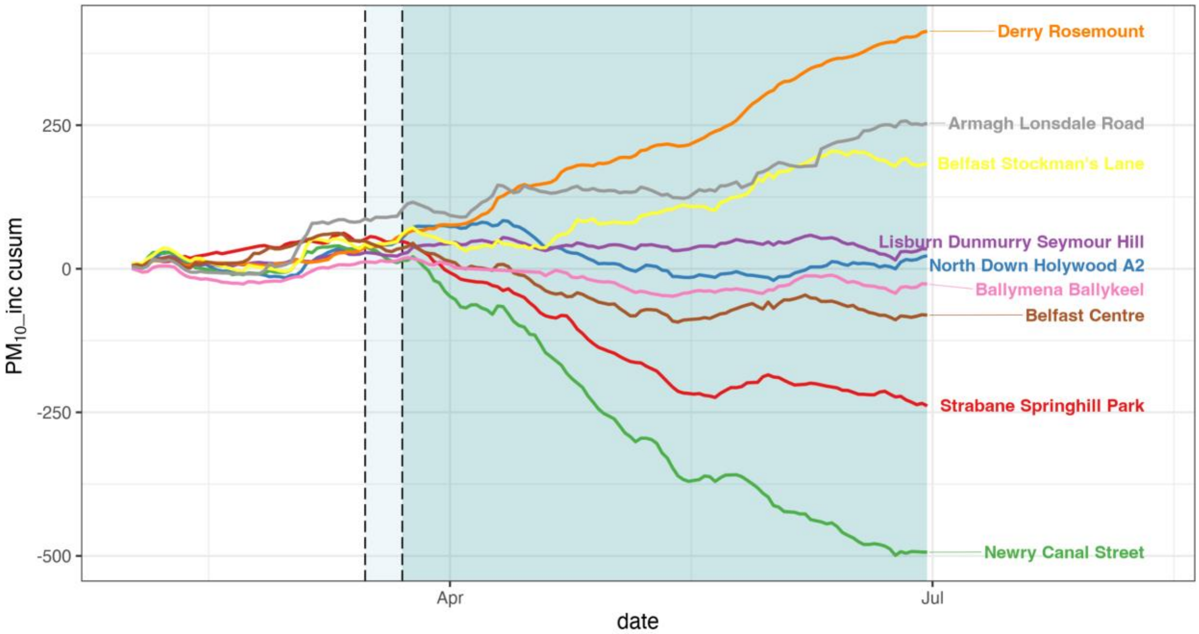
5.4 Analysis of Changes in PM_{10} Concentration

PM_{10} concentrations tend to be dominated by regional background levels rather than local primary emissions, which makes the analysis of changes in PM_{10} concentrations much more challenging. 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 assess the effects on local emissions, we consider the PM_{10} concentrations at Northern Ireland's urban sites **above** the regional background (that is, the ***urban increment*** in PM_{10}). The regional background is taken as the measured PM_{10} concentration at the rural Lough Navar site.

Figure 5-7 shows the cusum plot of measured minus BAU for the increment in PM_{10} concentrations above regional background (Lough Navar). Some sites show an increase in concentration and some show a decrease in concentration. The average increase in PM_{10} overall was approximately 1 µg m^{-3} above 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 5-7 Cusum plot of measured minus business as usual for the increment in PM_{10} concentrations above regional background (Lough Navar) at air pollution monitoring sites across Northern Ireland.



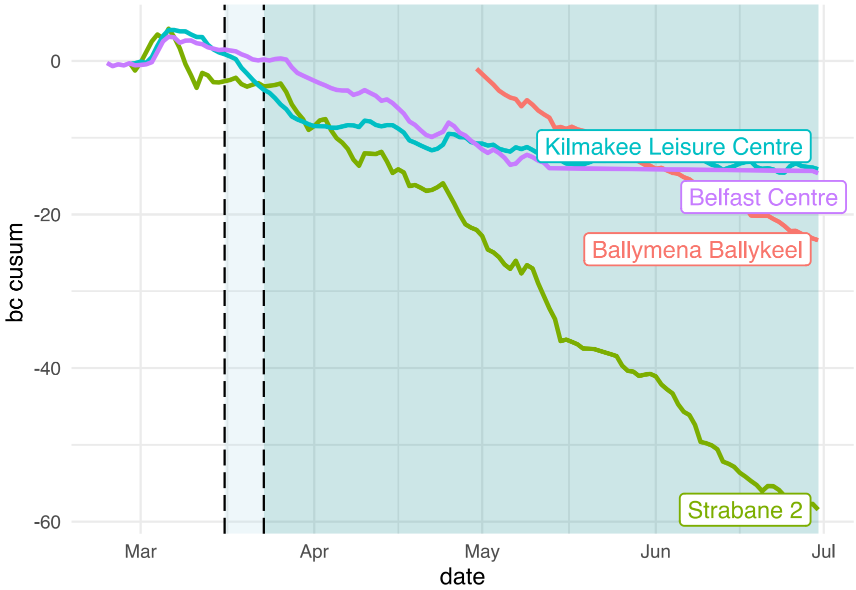
Unfortunately, it was not possible to carry out the same analysis for $PM_{2.5}$. The rural site (Lough Navar) only began monitoring $PM_{2.5}$ relatively recently, in July 2018. Therefore, there is insufficient rural $PM_{2.5}$ data to produce a robust model of the BAU scenario.

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.

5.5 Analysis of Changes in Black Carbon Concentration

Four sites in Northern Ireland measure black carbon (BC). Figure 5-8 shows a cusum plot of measured minus BAU black carbon at these four sites. Two sites have significant amounts of missing data but are shown for completeness. Shading indicates social distancing and lockdown periods as in previous figures. Strabane 2 (referred to as 'Strabane Springhill Park' in other networks) 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 5-7).

Figure 5-8 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 Conclusions

Emission Sources

- There were substantial reductions in electricity demand due to lockdown, estimated as approximately 12% in April 2020 and 8% in May 2020, returning to normal in June 2020.
- However, the resulting reductions in energy generation are only estimated to have resulted in a small reduction in emissions of NO_X: probably less than 1% of Northern Ireland's total.
- There was a very substantial drop in flights to and from both Belfast City Airport and Belfast International Airport. While it was not possible to quantify the impact on air quality, the reduction in air travel is expected to have reduced road traffic to and from the airports.
- Information provided by NIEA indicate the lockdown appears to have reduced emissions from NIEA-regulated industrial processes.
- 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).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. However, 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.

Meteorology

- There was a marked difference in weather conditions, 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 bringing relatively clean air from the Atlantic to Northern Ireland. Subsequently, over the period 16th Mar – 31st May the mean wind speed dropped and the wind direction was more variable: conditions potentially less conducive to good air quality. These natural 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.

Ambient Concentrations

- The cumulative sum (cusum) analysis revealed there were substantial reductions in measured NO_X and NO_2 concentrations as a result of the lockdown restrictions.
- On average, from 23rd March – 30th June, NO_X concentrations were 52% lower than the 'business as usual' (BAU) scenario and NO_2 concentrations were 44% lower than BAU.
- PM_{10} concentrations tend to be dominated by regional background levels rather than local emissions. Therefore, this study focussed on changes to the 'urban increment' PM_{10}, (the amount by which the PM_{10} at each urban site differed from the rural background concentration). Overall, there was no clear change in the PM_{10} urban concentration increment – some sites showed an increase and others a decrease.
- Black carbon measured at 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%. 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).

This study found a large reduction in concentrations of NOx and NO_2 associated with the lockdown restrictions and believed to be partly caused by the reductions in road traffic. However, the lockdown impacted other pollutants differently, partly because of the sources involved and partly because of the influence of changing weather conditions during the lockdown period. Therefore it would be an over-simplification to state that overall air quality in Northern Ireland improved during lockdown.

7 References

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