Estimation of ambient NO2 and PM2.5 concentration change in Wales during COVID-19 outbreak

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This brief summary provides a brief overview of data and results from a preliminary analysis carried out at Swansea University estimating the ambient reduction in ambient NO2 monitoring stations across Wales since the UK Government introduced restrictions through a 'lockdown' on March 23rd 2020. The full analysis to date with initial estimates for concentration reductions at 13 roadside, urban background, kerbside, urban centre and urban industrial sites, can be retrieved at: https://chemri.shinyapps.io/Wales_COVID19_Evidence/

This research is ongoing and will be updated as more data becomes available during the COVID-19 lockdown period. We have estimated NO2 concentration reductions using a multi-step process. Using trend analysis we are able to determine significant temporal changes in NO2 levels at sites since lockdown. Using random forest (RF) models we are able to predict the expected **meteorologically normalized NO2 levels** per day to compare **against measured daily average NO2 levels** at each location. This permits a comparison of **median residual ambient NO2 differences** (between predicted and measured levels) between pre- (01/01/2020 – 23/03/2020) and post-lockdown periods across monitoring stations. Datasets are described at the end of the summary.

We have developed an online tool, updated daily, using our models to track pollution change in Wales: https://chemri.shinyapps.io/upload/

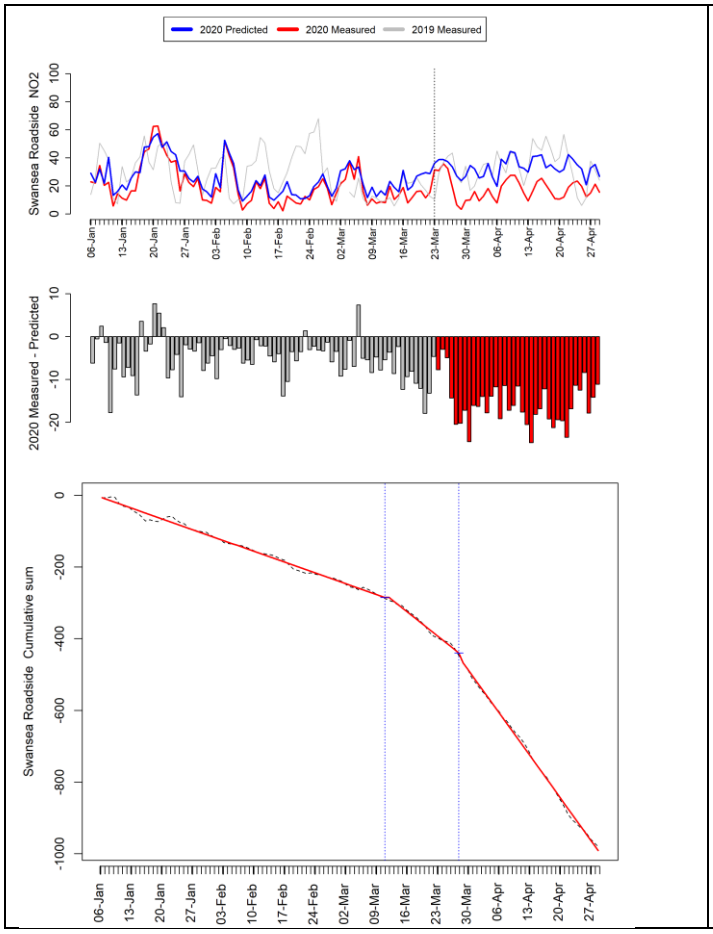
The example plots in Figure 1 are for Swansea Roadside monitoring station and demonstrate the model outputs:

(i) Measured (red line) and RF model meteorological normalised predicted (blue line) average NO2 levels for each day in 2020. The start of COVID-19 lockdown on March 23rd 2020 is highlighted.
(ii) Daily residual differences between measured and RF weather normalized model predicted average NO2.
(iii) Estimated significant breakpoints identified by trend analysis (on cumulative sum of residual differences).

Medians of residual differences between model predicted and measured NO2 levels (µg/m^3) and boxplots of residual distributions are also shown alongside each plot for both pre- and COVID-19 post-lockdown. Differences between the median NO2 levels in both these periods are provided along with corresponding p-values. The following table summarises the decrease in median NO2 following lockdown on 23rd March relative to all days prior in 2020. The NO2 reductions at the urban industrial site at Port Talbot Margam and the urban background site at St Julian's Comprehensive School in Newport were not statistically significant. Excluding these sites, the mean difference in NO2 reduction across the remaining 11 sites is -8.96 µg/m^3 (SE=1.47).

	Swansea Roadside	Swansea Morriston	Hafod DOAS	St Thomas DOAS	Cwm Level Park	Cardiff Centre	Newport St Julians	Newport M4	Hafod-Yr-Ynys	Port Talbot Margam	Chepstow A48	Rhondda Pontypridd	Wrexham
NO2 reduction	-11.9	-7.5	-12.5	-8.8	-4.8	-12.6	-1.4	-7.9	-20.7	-3.4	-9.2	-6.5	-3.4

Figure 1.



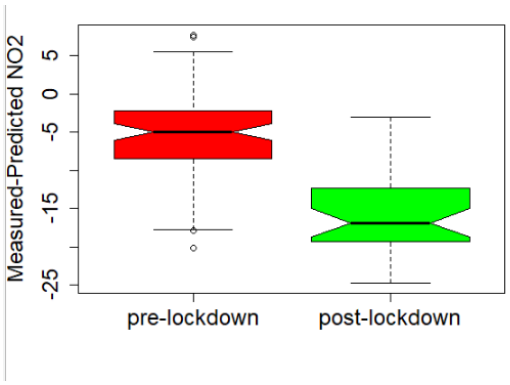
Swansea Roadside

<u>Medians of residual NO2 differences pre- and post-lockdown (µg/m^3):</u>

Median difference pre-lockdown = -4.93

Median difference post-lockdown= -16.88

Difference (NO2 reduction): **-11.95** (P < 0.0001)

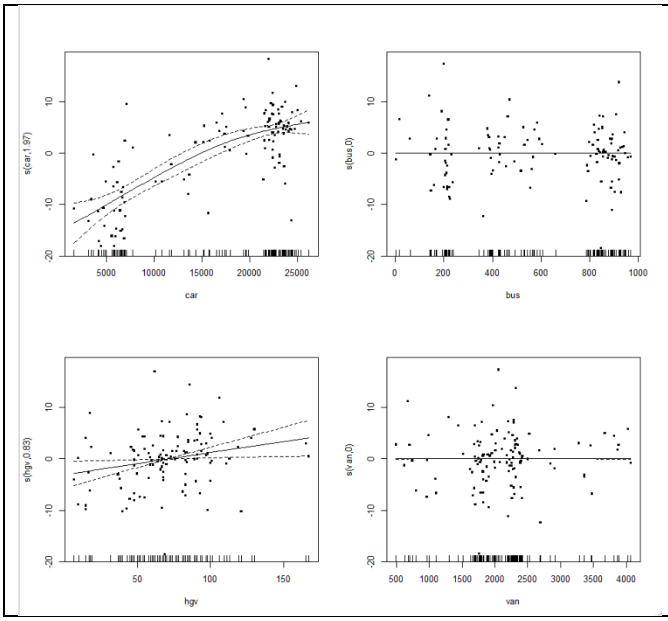


We have further extended our analysis by using generalized additive models to predict the impact of traffic volume change different classes of traffic (car, van, bus and HGV) on the daily average predicted NO2 change at four roadside monitoring stations in the Swansea urban area during this period.

To estimate the relationship between traffic reduction and ambient NO2 levels since COVID-19 lockdown, we calculated the NO2 residual differences between RF model predicted meteorological normalized and measured NO2 data at Swansea Roadside, Swansea Morriston, Swansea Hafod DOAS and Swansea St Thomas DOAS over a ten year period and used as a dependent variable to train GAMS models per site with total daily traffic count data for cars, light vans, HGV vehicles and buses as independent variables. Thus, each GAMS model predicts daily average residual NO2 levels when using daily traffic count data from 2020 as input. Each GAMS model could also reveal whether the change in volume of any vehicle type was significantly associated with change in NO2 levels since COVID-19 lockdown. Non-significant terms were retained in the optimal models to control for those vehicle types when predicting associations of cars with NO2 reduction since COVID-19 lockdown.

The plots in Figure 2 show an example for Swansea Roadside of the linear and non-linear relationships between vehicle type volume and predicted residual change in NO2 models. For all sites, there was a positive and significant linear, or near linear, relationship between the volume of cars and NO2 residual values. There was no similar relationship observed for cars, HGV vehicles or buses at three sites but HGV had a significant relationship at Swansea Roadside.

Figure 2.



Swansea Roadside

Vehicle	Estimated df	p-value
s(car)	2	< 2e-16 ***
s(bus)	0	0.97449
s(hgv)	0	0.00719 **
s(van)	0	0.30709

R-sq.(adj) = 0.638
Deviance explained = 64.7%

The following tables show the daily median counts of vehicle type for pre- and post-lockdown at each of the four monitoring sites. The tables also show the predicted reduction in NO2 from the GAMS models when the volume of cars is entered at median values observed for either the pre- or post-lockdown periods (controlling for vans, HGV and bus volumes). Thus, the models permit the local authority to estimate the median daily reduction in NO2 that could occur by a unit reduction of daily median cars. For example, at Neath Road (corresponding to the Swansea Hafod DOAS) within an existing Air Quality Management Area (AQMA), the model predicts that a 10% reduction in cars (1100) without reducing other vehicle types would lead to approximately a median daily reduction of 2 µg/m^3 in NO2.

Swansea Roadside							
	Daily median volumes				Predicted reduction in NO2 (µg/m^3)		
	Pre-lockdown	Post-lockdown	Difference	P value	Car volume at Pre-lockdown	Car volume at Post-lockdown	Difference
Cars	22440	6017	16423	<0.0001	-4.23	-13.34	**-9.11**
Light vans	2280	1694	586	<0.0001			
HGV	82	46	36	<0.0001			
Bus	836	214	623	<0.0001			

Swansea Morriston Roadside							
	Daily median volumes				Predicted reduction in NO2 (µg/m^3)		
	Pre-lockdown	Post-lockdown	Difference	P value	Car volume at Pre-lockdown	Car volume at Post-lockdown	Difference
Cars	32431	10310	22121	<0.0001	-2.35	-8.40	**-6.05**
Light vans	2280	1694	586	<0.0001			
HGV	65	24	41	<0.0001			
Bus	110	74	36	<0.0001			

Swansea Hafod DOAS							
	Daily median volumes				Predicted reduction in NO2 (µg/m^3)		
	Pre-lockdown	Post-lockdown	Difference	P value	Car volume at Pre-lockdown	Car volume at Post-lockdown	Difference
Cars	15225	4225	11000	<0.0001	-4.63	-24.49	**-19.86**
Light vans	1316	534	782	<0.0001			
HGV	77	12	65	<0.0001			
Bus	108	38	70	<0.0001			

Swansea St Thomas DOAS							
	Daily median volumes				Predicted reduction in NO2 (µg/m^3)		
	Pre-lockdown	Post-lockdown	Difference	P value	Car volume at Pre-lockdown	Car volume at Post-lockdown	Difference
Cars	22774	6046	16728	<0.0001	8.56	-1.54	**-10.10**
Light vans	1102	545	557	<0.0001			
HGV	70	31	39	<0.0001			
Bus	97	43	54	<0.0001			

Finally, we have also carried out an initial assessment to determine whether ambient reduction had occurred in PM2.5 levels in South Wales. PM2.5 have however been increased substantially since lockdown, relative to pre-lockdown levels, at all monitoring stations on four occasions for periods of days. We have further explored whether these regional increases were due to transboundary effects and non-local sources. Using hourly satellite and ensemble modelled PM2.5 data retrieved from the Copernicus Atmosphere Monitoring Service (CAMS) for North Western Europe we were able to determine that all four temporal episodes of increased PM2.5 levels were occurring across a wide geographical area extending across the South of England and into France.

Figure 3.

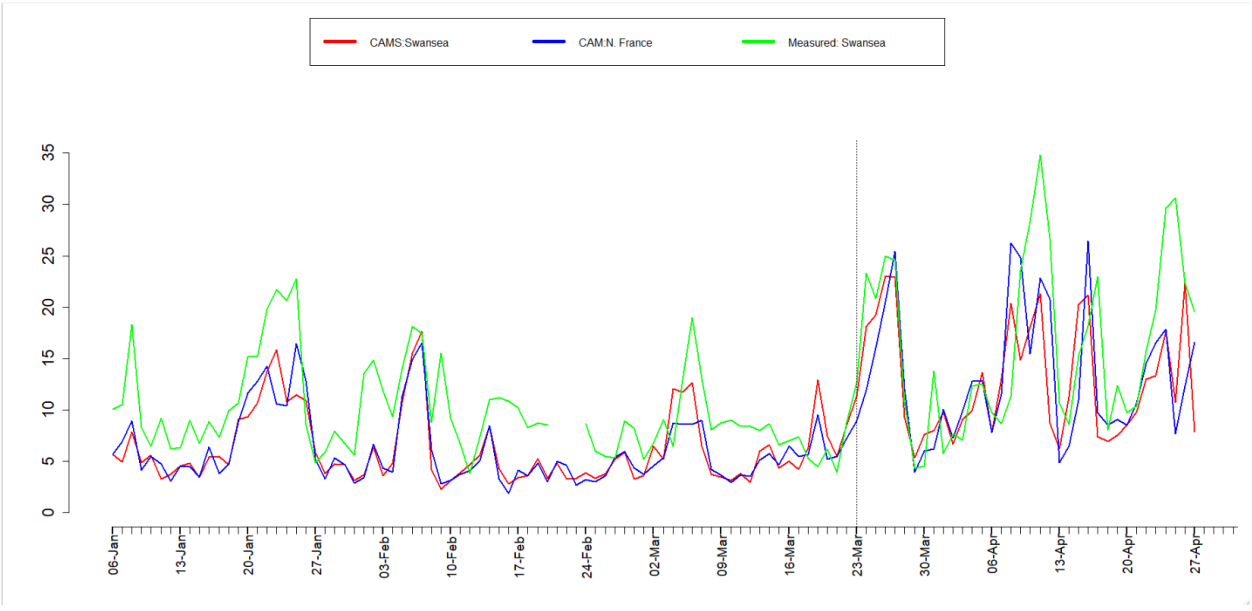


Figure 3 shows daily levels of PM2.5 throughout 2020 for measured data at Swansea Port Tennant monitoring station and CAMS modelled data for a location in the North of France (30km South East from Calais) and Swansea. The CAMS data for Swansea can be considered as urban background over a 10km by 10km area. Whereas, with these transboundary effects, it is difficult to determine change in ambient PM2.5 levels in Wales, the data indicates the need to establish whether the elevated levels of PM2.5 since lockdown have had a detrimental impact on vulnerable people during this period.

We are working with colleagues at the Farr Institute in Swansea University Medical School and SAIL databank to assess potential impacts of increased PM2.5 on vulnerable groups during this period, particularly respiratory and cardiovascular patients, within the Welsh population.

Datasets used:

Air pollution and modelled meteorological data: Hourly measurements for NO2 (µg/m^3), modelled wind speed (m/s), modelled wind direction (°) and modelled temperature (°C) from 01/01/2010 (or 2011) to the current day are retrieved daily for 13 AURN monitoring stations from Air Quality Wales through functions in the R statistical environment 'openair' package. The sites include: Cardiff Centre (Urban centre), Swansea Roadside (Roadside), Swansea Morriston Roadside (Roadside), Swansea Hafod DOAS (Roadside), Swansea St Thomas DOAS (Roadside), Swansea Cwm Level Park (Urban background), Newport St Julians Comp School (Urban background), Newport M4 Junction 25 (Roadside) , Hafod-Yr-Ynys (Kerbside), Port Talbot Margam (Urban industrial), Chepstow A48 (Roadside), Rhondda Pontypridd Gelliwastad Road (Roadside), Wrexham (Roadside).

Hourly measurements for PM2.5 (µg/m^3), modelled wind speed, modelled wind direction and modelled temperature (µg/m^3), from 01/01/2019 to the current day are retrieved daily in the same manner for 9 monitoring stations at Cardiff Centre, Swansea Roadside, Swansea Port Tennant Roadside, Newport St Julians Comp School, Port Talbot Margam, Chepstow A48, Wrehxam, Caerphilly Fochriw (Roadside), Anglesey Brynteg (Other).

Measured meteorological data: Hourly average measured data for wind speed (m/s), wind direction (°), temperature (°C) and relative humidity (%) from 01/01/2010 to present day for Cwm Level Park 30m mast (Swansea Council).

Traffic count data: Hourly traffic count data from 01/01/2010 to present day (Swansea Council) for 4 automatic traffic counters within the city: Carmarthen Road (4, lanes, adjacent to Swansea Roadside AURN), Fford Cwm Tawe (4 lanes, adjacent to Swansea Morriston Roadside AURN), Neath Road (2 lanes, adjacent to Swansea Hafod DOAS) and Pentreguinea Road (2 lanes, adjacent to Swansea St Thomas DOAS).