NSW GOVERNMENT

Department of Planning and Environment

Impact of Liddell Power Station decommission on local and regional air quality

- **A report prepared for the NSW Environment Protection Authority**

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Summary

Liddell Power Station was a coal-fired power station located in the Upper Hunter region of NSW and was fully decommissioned on 28 April 2023. Under the request from the NSW EPA, The Department of Planning and Environment conducted a modelling study to examine the potential for any improvement to air quality after the closure of the station.

A modelling system was used to simulate the concentrations of air pollutants and therefore investigate the impact of the retirement of the power station on local and regional air quality.

Two simulations were performed for the NSW greater metropolitan region (GMR) to test if the air quality is affected:

1) The base case simulation included all human-made (anthropogenic) emission sources, including emissions from the power station.
2) The test case simulation included all human-made emission sources, excluding emissions from the power station.

The analysis was focused on the differences between the base case and test-cast simulations. The results indicate that the shutdown of the station can lead to a slight decrease in average NO and NO_2 levels in the GMR, with the greatest decrease in areas near the power station. In contrast, closer to the power station, there is a slight increase in ozone levels, which gradually decrease with distance from the facility. The decrease in average $PM_{2.5}$ levels is also noticeable. Initial calculations show that this decrease is estimated equivalent to taking around 125,000 cars off the road.

In conclusion, the predicted changes in pollutants (NO, NO_2, O_3 and $PM_{2.5}$) are small across the GMR, with a potential for slightly improved air quality on the local and regional scales. Further details can be found in the report sections below.

Introduction

Coal-fired power plants are responsible for a significant portion of the nitrogen oxides (NO_x = NO and NO_2), particular matter (PM) and Carbon dioxide (CO_2) emitted in NSW. These emissions impact human health and the environment in a variety of ways. Specifically, NO_x contributes to the formation of tropospheric ozone (O_3), and NO_x and SO_2 contribute to the formation of $PM_{2.5}$ (fine particulate matter with a size less than 2.5 microns in diameter). NO_2, SO_2, ozone, and $PM_{2.5}$ are all criteria pollutants, while CO_2 is a greenhouse gas.

Ozone formation from power-plants depends on the amount of NO_x and biogenic emissions and are strongly influenced by the prevailing meteorology. Meanwhile, PM formation from NO_x and SO_2 depends strongly upon meteorology and concentrations of ammonia from areas downwind of the plant. These factors, together with population density and baseline morbidity and mortality rates, influence the health impacts of power-plant pollution per unit of emissions.

Since CO_2 has very long lifetime and is well- mixed in the atmosphere, the expected climate impacts of CO_2 will be independent of the location and timing of emissions.

Impacts of power-plant emissions on local and regional air quality are often simulated with regional chemical transport models, such as the coupled Conformal Cubic Atmospheric Model (CCAM) and CSIRO Chemical Transport Model (CTM) system (hereafter, CCAM–CTM) that has been widely adopted in Australia. These models provide the best available representation of a wide range of physical and chemical processes that influence the formation of ozone and PM from precursor gases.

Liddell Power Station (LPS) was a previous coal-fired power station located in the Upper Hunter region of NSW. It was decommissioned at the end of April 2023.

The current project seeks to investigate the impact of the retirement of LPS on local and regional air quality. The analysis involved applying the CCAM–CTM modelling system to evaluate the effects of the change in air emissions from the LPS.

CCAM-CTM has been extensively used in Australia for air quality assessments (Chang et. al., 2018; Monk et al., 2019; Duc et. al., 2020; Guérette et. al., 2020). The system has been peer-reviewed through a wide publication of scientific papers in international journals submitted by several research groups. In NSW, the model has been used for major research projects including the Sydney Air Quality Study (SAQS)- Stage1 and Stage 2 (DPE, 2023. https://www.environment.nsw.gov.au/topics/air/research/current-research/sydney-air-quality-study).

This report describes the methodology and discusses the results of the photochemical modelling, specifically how the closure of LPS as an emission source, impacts local and regional air quality.

Methodology

Emissions from power stations, primarily NO_x and sulfur dioxide (SO_2), affect air quality in the local and regional areas downwind as the plumes can be widely dispersed. The main emitted air pollutants are NO_x (nitric oxide (NO) and nitrogen dioxide (NO_2)), SO_2 and PM (particulate matter). NO_x has the potential to react with Volatile Organic Compounds (VOCs) and form tropospheric ozone (O_3) under sunlight conditions and is involved in chemical reactions with ammonia (NH_3) and SO_2 to form secondary inorganic aerosols. The photochemical process of these air pollutants is mostly non-linear and can be affected by multiple factors and complex chemical reactions.

During operations, LPS was a major emission source of air pollutants in the GMR and contributed to local and regional air pollution. To evaluate the impact of a change in emissions from a pollution source, typically a chemical transport model is selected to estimate the

potential of photochemical air pollutant formation (such as NO_2 and O_3) over a selected study area. Different scenarios can be undertaken to assess the sensitivity of emission changes on air quality. In general, two modelling scenarios are usually selected including one base-case emission scenario with all known emission sources captured in the emission inventory covering the selected modelling domain. A second test-case modelling scenario where emissions from a selected source are perturbated in the emission inventory to reflect anticipated changes (in this case the removal of emissions from LPS). The difference in predicted air pollutant concentrations across the modelling domain will be used as indicator to assess the impact of the perturbated emission changes on the air quality.

Two simulations were performed using the CCAM-CTM system in the present project. The base case for the 2013 calendar year was simulated with all anthropogenic emission sources, including LPS operating for the duration of the model period. The base case model results for 2013 have been validated and published in several DPE reports and published journal papers. The test-case scenario (S1) was simulated as in the base case but with the LPS emissions removed (i.e., including all other anthropogenic emission sources). The results from the base case simulation were examined and the difference between the base case and the S1 scenario were analysed and evaluated.

The NSW 2013 air emissions inventory (NSW AEI) was used in this study. It is acknowledged the AEI for 2013 might not reflect the current, real-world emission conditions in NSW GMR. However, we expect the findings remain valid, as the research was designed to examine the changes in predicted pollution levels between scenarios.

Emission preparation

For this study, we used the latest NSW 2013 air emissions inventory (NSW AEI) covering all anthropogenic sources within the NSW GMR. The LPS source characteristics are specified in the NSW emission inventory as shown in Table 1. Emissions sources from LPS include two stacks, each with two boilers.

Table 1 Stack parameters used to model LPS

Stack Parameters	Value (stack 1)	Value (stack 2)	Units
Latitude	-32.3709	-32.3723	degrees
Longitude	150.9787	150.9784	degrees
Stack height	100.	100.0	m
Stack diameter	10.0	10.0	m
Exit Velocity	20.0	16.0	m/s
Exit temperature	170.0	138.0	^oC
Flow Rate	1570.8	1256.6	m^3/s

Table 2 shows the estimated emissions from LPS on a typical weekday for a range of chemical species, in comparison with the total for all coal-fired power stations in the GMR. LPS accounted for between 8.7% and 13.8% of the total air emissions from all coal-fired power stations.

The CCAM-CTM model simulation was run for one calendar year from 1 January to 31 December 2013. It was assumed that the LPS source was operating for the duration of the model period. This conservative assumption has been adopted to capture the potential worst-case emissions scenario.

Table 2 Air emissions estimates from LPS and all coal-fired power stations in GMR

Chemical species	LPS (kg/day)	All coal-fired stations (kg/day)	LPS percentage contribution to GMR emissions
NO	20,769	209,197	10.0%
NO_2	1,676	16,880	10.0%
CO (carbon monoxide)	1,683	15,128	11.1%
SO_2	56,308	499,619	11.3%
PM_{10} (particulate matter)	511	5,861	8.7%
ALD2 (acetaldehyde)	6	62	9.6%
Toluene	31	326	9.5%
CH_4 (methane)	1,689	15,187	11.1%
NH_3	4	29	13.8%

Model description

The CCAM-CTM modelling system was used to simulate spatial and temporal concentrations of air pollutants. Meteorological fields including wind velocity, turbulence, temperature, radiation and the water vapour mixing ratios are produced by CCAM. CTM uses the extended Carbon Bond 5 mechanism (CB05) that consists of 65 gas phase species, 19 aerosol species and 172 reactions. Figure 1 shows the components of the modelling system (meteorology, emission inventory and CTM).

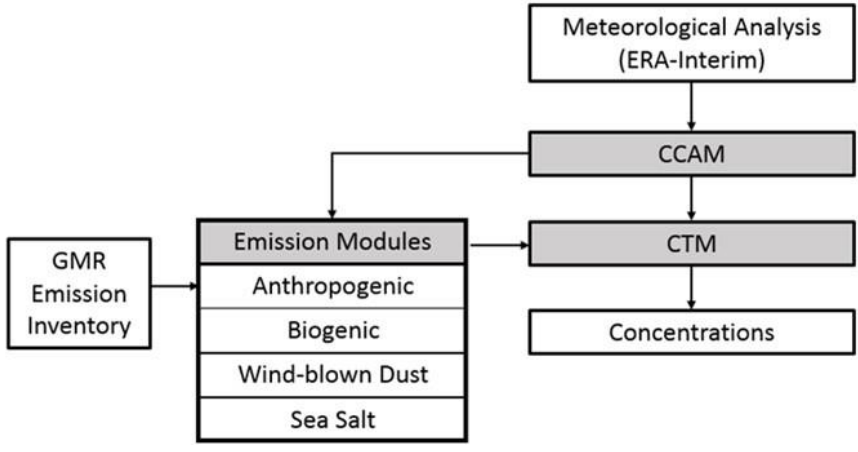

Figure 1 Schematic diagram of the CCAM–CTM modelling system

A limitation of the NSW AEI for 2013 is that it does not provide emission estimate for $PM_{2.5}$, which is of interest for human health. Therefore, this study has adopted a simple conversion factor to calculate $PM_{2.5}$ from PM_{10} (particulate matter with a size less than 10 microns in

diameter). The updated $PM_{2.5}/PM_{10}$ ratios that were used to create the emission files for CCAM-CTM are presented in Table 3.

Table 3 $PM_{2.5}/PM_{10}$ ratios used in CCAM-CTM

Source	NSW AEI	CCAM-CTM	$PM_{2.5}/PM_{10}$ ratios
Inventory Sources	*CIT*	*CTM*	*2013 Inventory*
Aircraft	aems	gse	0.983
Commercial Vehicles and Equipment	aems	gse	0.970
Industrial Vehicles and Equipment	aems	gse	0.970
Locomotives	aems	gse	0.970
Ships	aems	gse	0.920
Industrial fugitives (excl wind erosion)	aems	gse	0.150
Domestic-Commercial (total exc. solid fuel burning)	aems	gse	0.940
All - Non-Exhaust PM	aems	gse	0.532
Diesel – Exhaust	mvems	vdx	0.970
Others – Exhaust	mvems	vlx	0.953
Petrol – Exhaust	mvems	vpx	0.953
Solid Fuel Burning (Domestic)	aems	whe	0.963
Generation of electrical power from coal	pems	pse	0.408
Generation of electrical power from gas	pems	pse	0.998
Industrial point sources (except for coal and gas)	pems	pse	0.680

All the coal-fired power stations are grouped into selected emission files and the other emission sources are grouped into corresponding source categories.

Results

The CCAM-CTM air quality model predicts the concentrations of selected pollutants on an hourly basis at each grid point in the domain GMR at 3km by 3km resolution. These gridded data are then aggregated over the 2013 modelling period to obtain annual averages and annual averages of daily maxima for individual pollutants of interest.

The results for the base case simulation and the difference between the base case and S1 (test-case) scenario simulations are summarised in this section. The presentation is focused on annual averages and annual averages of the daily maximum of the four pollutants of interest, i.e., NO, NO_2, O_3 and $PM_{2.5}$.

Base case

Annual average

The precise changes in the modelled O_3 resulting from power plant NO_x emissions are a complex interaction of the plant NO_x emissions, level of ambient NO_x where the plume is emitted and dispersed, VOC emissions in the vicinity and along the plume trajectory and meteorological factors such as sunlight availability. Regions can be classified as NO_x-limited

or VOC-limited to highlight the potential reactivity capacity of the ambient air in terms of photochemical smog production.

Figure 2 shows the base case 2013 annual average of NO, NO_2, O_3 and $PM_{2.5}$ concentrations over the GMR as predicted by the CCAM-CTM air quality modelling system. In general, high NO and NO_2 concentrations occurred in the so-called "NO_x-rich" areas of the Upper Hunter, the Central Coast and Sydney, where power station emissions or motor vehicles emission sources dominate.

In contrast, these NO_x-rich regions have lower O_3 levels, with high O_3 concentrations mostly occurring in the northwest and western parts of Sydney where NO_x-limited photochemical regime frequently happens during summertime (Figure 2). This is consistent with local experience of O_3 precursor emissions in the Sydney basin. Most NO_x emissions occur over central Sydney and can be transported further inland (west) by easterly to north-easterly sea breezes, typically between early morning and late afternoon. The O_3 spatial pattern is a classic representation of interactions between NO_x and VOC emissions in the GMR.

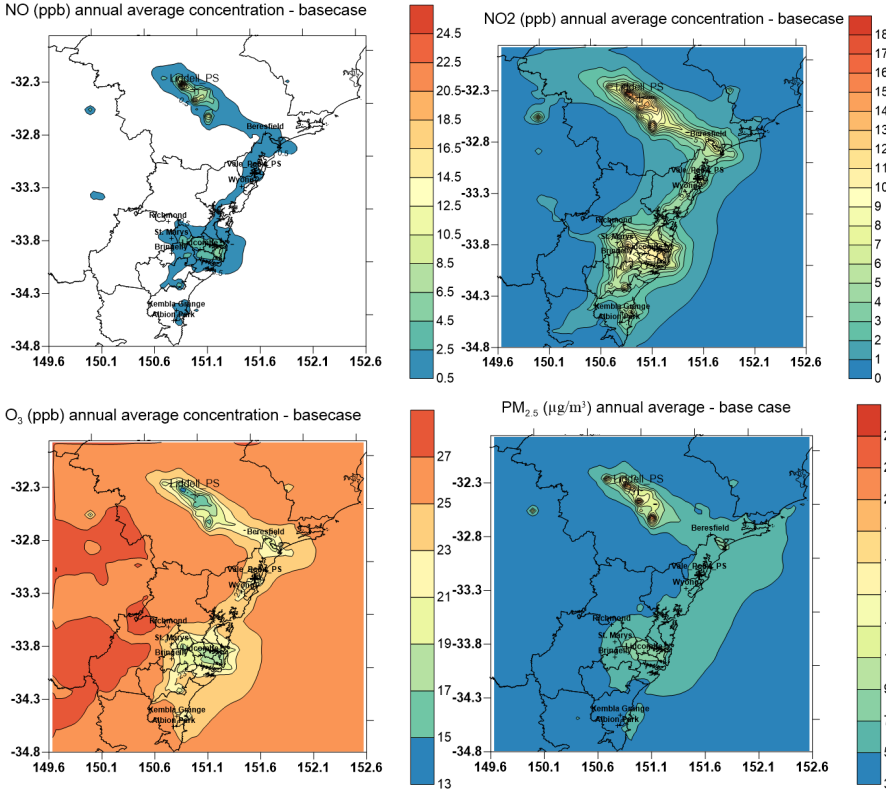

Figure 2 Annual average of NO, NO_2, O_3 and $PM_{2.5}$ as predicted from CCAM-CTM over the GMR in 2013 – base case

For $PM_{2.5}$, high concentrations were observed in the Upper Hunter and Sydney regions. Wood heating (especially during wintertime) and mining activities (limited to Upper Hunter) caused elevated concentration of $PM_{2.5}$. Emissions from point sources (such as power station in the

Central Coast and Lower Hunter) were lower when compared to the previously mentioned regions.

These results are considered typical of the GMR, with the spatial distribution and concentrations similar to those shown in previous studies.

Difference between base case and S1 scenario simulations

Annual average

Figure 3 shows the difference between the base case and S1 scenario in annual averages of NO, NO_2, O_3 and $PM_{2.5}$. These results show that the difference is small. For NO, the maximum difference is 1 ppb, while for NO_2 the value is 0.75 ppb. The results show that annual average NO and NO_2 concentrations decrease with Scenario 1 as compared to the base case. The most significant decrease of NO and NO_2 occurs in the area of Upper Hunter near the LPS.

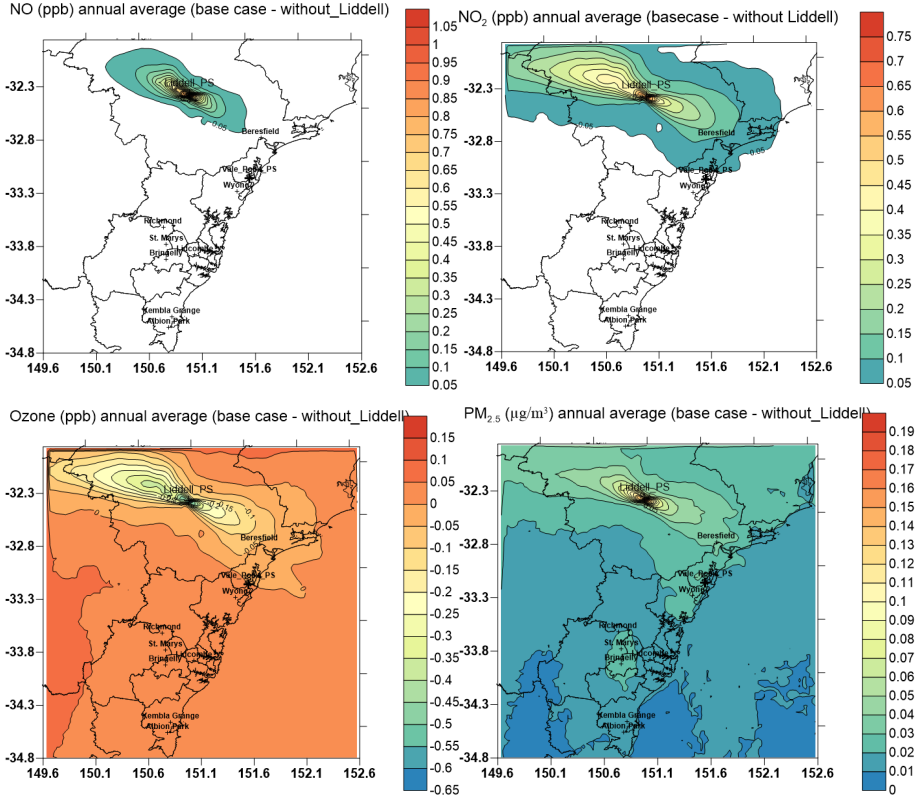

Figure 3 Difference in simulated annual average of NO, NO_2, O_3 and $PM_{2.5}$ between base case and S1 scenario as predicted by CCAM-CTM model over the GMR in 2013

For O_3, the reduction of NO_x emissions from LPS resulted in a slight increase of O_3 over a narrow area near the facility - but this increase is gradually decreasing over areas further away from the facility. The increase in O_3 is about 0.65 ppb max around LPS. This increase could be related to the absence of NO that used to titrate the available O_3 over this area.

The effects of NO_x emission reductions/elimination on O_3 are influenced by whether the NO_x plume is in a relatively lower NO_x or higher NO_x regime. This is driven by the characteristic of complex non-linear dependence of O_3 on NO_x. At lower NO_x, the plume chemistry favours conversion of NO to NO_2 by peroxy radicals (OH) leading to enhanced production rates and yields of O_3. At higher NO_x, radical loss primarily through $OH+NO_2$ and reaction of O_3 with NO to form NO_2 result in lower ozone levels.

$PM_{2.5}$ annual averages decrease in most of the domain. The maximum change is at (near) LPS (about 0.19 $\mu g/m^3$).

Summary statistics of predicted annual average concentrations over the grid domain

Another way to summarise the difference between the base case and S1 simulations is to plot the boxplots of concentration differences of all grid cells in the GMR modelling domain. Using this method, we can visualise the overall distribution of concentration differences in all grid cells for each pollutant. Figure 4 shows the box plots of annual average differences in the GMR domain between base case and S1 scenarios for NO, NO_2, O_3 and $PM_{2.5}$. Over the whole domain, the S1 scenario reduces the NO, NO_2 and $PM_{2.5}$ annual average as compared to the base case.

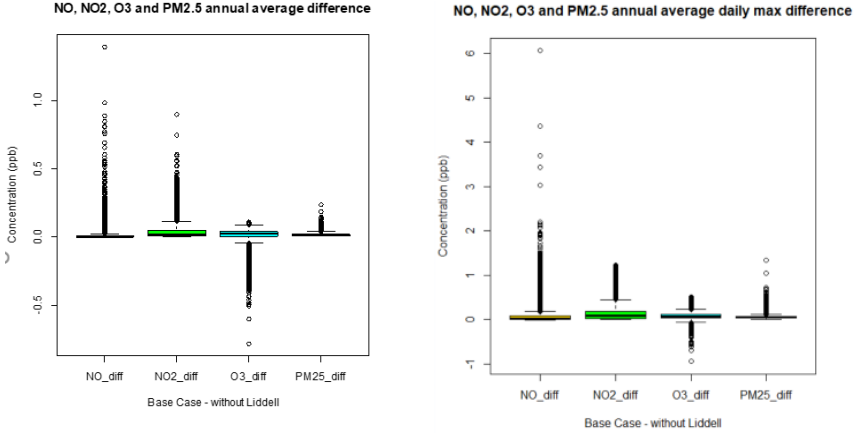

Figure 4 Box plots of differences in annual averages (left) and annual average daily maximum levels in the GMR domain between the base case and S1 scenarios for NO, NO_2, O_3 and $PM_{2.5}$

Over the whole domain, the S1 scenario reduces the annual averages of daily maximum NO and NO_2 as compared to the base case.

Table 4 shows the summary statistics of differences between the base case and S1 simulations (i.e., base case – S1) in annual averages and annual average daily maximum values for NO, NO_2, O_3 and $PM_{2.5}$ in the GMR domain. Negative values in the table indicate that the base case values are less than the S1 scenario values, and vice versa.

The changes in NO, NO, O_3 and $PM_{2.5}$ concentration (annual average and annual average of daily maximum) from base case to S1 scenario are small but noticeable.

Table 4 Summary statistics for differences between the base case and S1 scenario simulations, with units for NO, NO_2 and O_3 in ppb and $PM_{2.5}$ in $\mu g/m^3$

	Min	Mean	1st quartile	Median	3rd quartile	Max

Base case - S1	Annual average	NO	-0.0028	0.014	0.001	0.0028	0.01	1.39
		NO_2	0.0015	0.046	0.0087	0.019	0.051	0.90
		O_3	-0.78	0.007	0.008	0.024	0.04	0.11
		$PM_{2.5}$	0.008	0.24	0.01	0.015	0.022	0.24
	Annual average of daily maximum levels	NO	-0.011	0.092	0.058	0.023	0.081	6.06
		NO_2	0.0016	0.156	0.021	0.081	0.194	1.23
		O_3	-0.94	0.078	0.044	0.071	0.117	0.51
		$PM_{2.5}$	0.013	0.0615	0.036	0.048	0.073	1.34

Time series of daily averages at Liddell PS and at a site in the Lower Hunter

The greatest influence on air quality from a change in emissions is usually near the source for the primary emission of NO_x, in this case near LPS. This can be assessed by comparing the daily change in concentration of air pollutants during the year for different scenarios.

As shown in Figure 5 for the grid point nearest to LPS, daily average concentrations of NO, NO_2, O_3 and $PM_{2.5}$ in 2013 for the base case and S1 emission scenarios, showed distinguishable reductions in daily average NO and NO_2 concentrations from the base case to the S1 scenario. For both O_3 and $PM_{2.5}$, there is small difference in the predicted concentrations between scenarios at the LPS grid point.

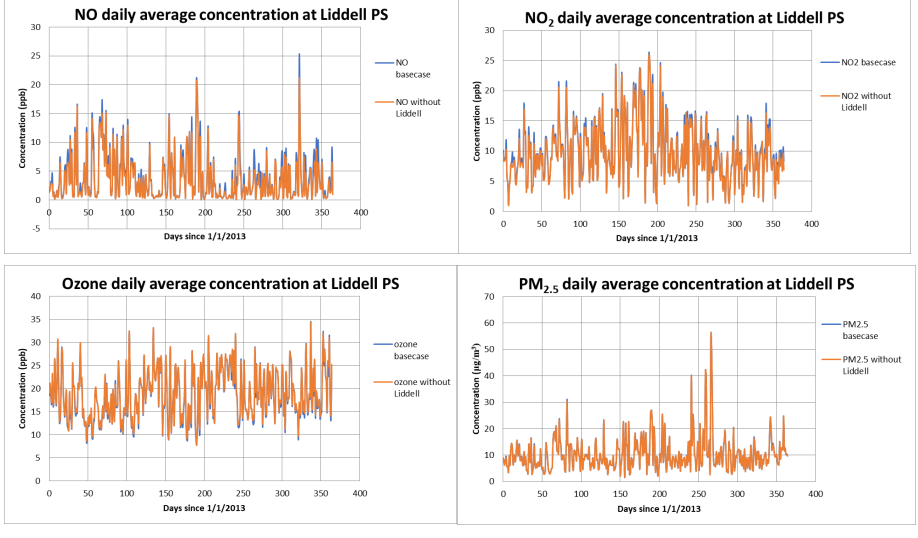

Figure 5 Plots of predicted daily average NO, NO_2, O_3 and $PM_{2.5}$ concentrations at LPS for 2013 from the base case and S1 scenario simulations.

Similarly, Figure 6 shows the plots of predicted daily maximum concentrations of NO, NO_2, O_3 and $PM_{2.5}$ for 2013 at a distant site, Beresfield in the Lower Hunter from the base case and S1 scenario simulations. There are some differences in the pollutant concentrations, but they are small and considered insignificant.

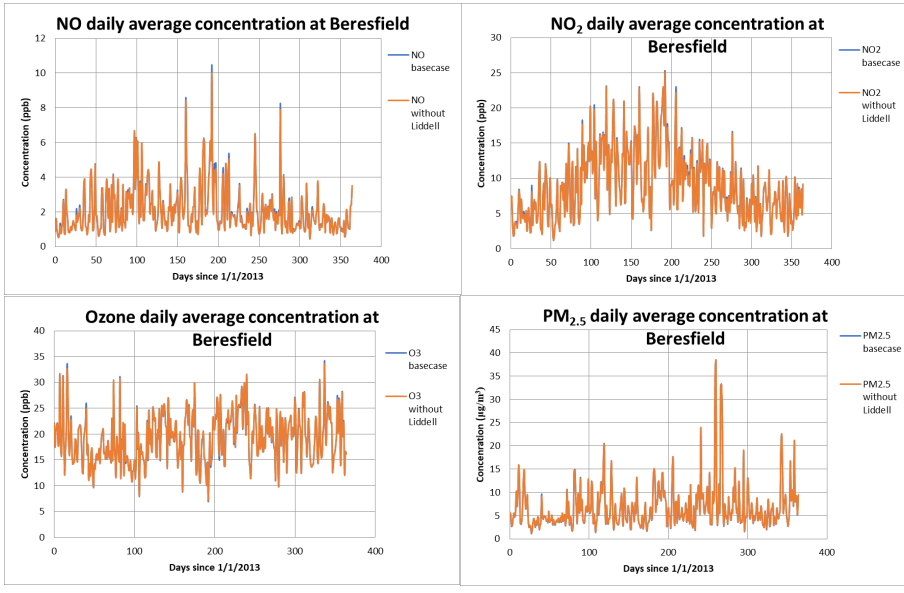

Figure 6 Plots of predicted daily average NO, NO_2, O_3 and $PM_{2.5}$ concentrations for 2013 at Beresfield from the base case and S1 scenario simulations.

Time series of daily maximum pollutant concentrations at LPS

Pollutants are often assessed as against relevant air quality standards in NSW (Australia). Hence, we also examined difference in daily maximum concentration levels for individual pollutants (Figure 7).

The results show some reductions in maximum NO and NO_2 levels at the LPS site, but with differences generally negligible in O_3 and $PM_{2.5}$ daily maximum concentrations.

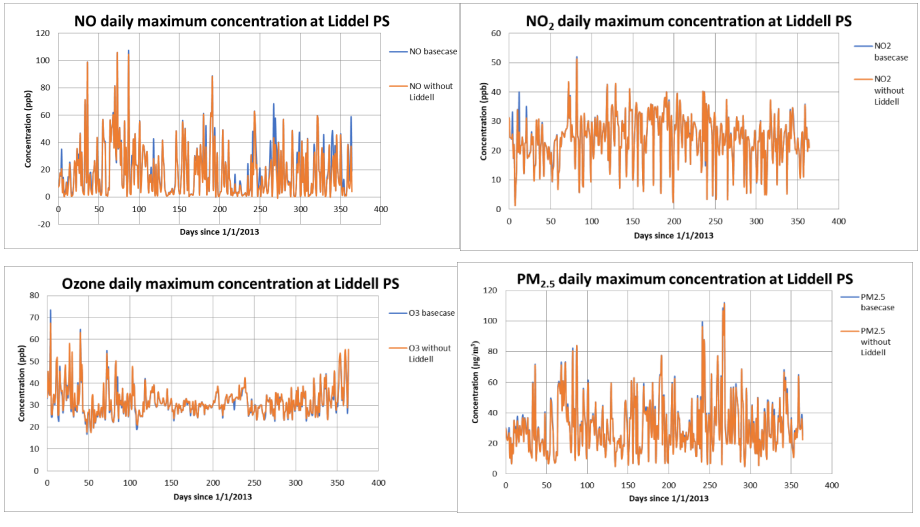

Figure 7 Plots of predicted daily maximum NO, NO_2, O_3 and $PM_{2.5}$ concentrations at LPS for 2013 from the base case and S1 scenario simulations.

Discussion

Motor vehicles are another major source of NO_x in NSW, produced by the combustion of fuels. The following is an attempt to find the equivalence between the amount of NO_x reduction resulting from the closure of Liddell power station to the number of motor vehicles that potentially emit the same amount of NO_x emissions.

The Sydney Air Quality Study – Stage 2 (SAQS 2, DPE 2023) modelled and analysed the contribution of various emissions sources and the related population exposure in the GMR. Based on the output from this study, we can estimate the effect of removing the Liddell power station in terms of its equivalence to other major emission source removal such as motor vehicles. The annual $PM_{2.5}$ (population weighted exposure) concentration levels from Table 2 in DPE (2023; the SAQS stage 2), are presented in Table 5 .

Table 5 Major human-made source groups and their contributions to population-weighted annual average $PM_{2.5}$ (pwaa-$PM_{2.5}$) concentrations (μg/m³) in GMR. Adapted from DPE (2023)

Power stations	0.213
Wood heaters	1.261
On-road motor vehicles (exhaust)	0.379
On-road motor vehicles (non-exhaust)	0.134
Non-road diesel and marine	0.186
Industry	0.623
Domestic-commercial	0.204
Other (model uncertainties associated with non-linear processes)	0.070
All human-made sources	3.070

The assumption was that the Liddell power station contributes about 10% of all Power stations source NO_x emission (and other pollutants) and hence 10% of the $PM_{2.5}$ annual average (population weighted exposure) concentration.

By comparing to all on road motor vehicle (exhaust only), the proportion is calculated as

(0.213 * 10%)/ 0.379 = 0.0562 or 5.6%

This is equivalent to 5.6% of vehicle effects on annual average $PM_{2.5}$ (population weighted exposure). From the NSW 2013 Emissions Inventory, the total number of passenger cars is 2,229,131 in the whole GMR. Hence, the change of 5.6% in population weighted average $PM_{2.5}$ alone is equivalent to a reduction of approximately 125,000 cars on the road.

Conclusion

This air quality modelling study has used CCAM-CTM to simulate the impact of the decommissioning of LPS on local and regional air quality in the GMR. Four pollutants of interest are considered, namely NO, NO_2, O_3 and $PM_{2.5}$.

The simulations show that the shutdown of LPS resulted in a decrease in annual averages and annual averages of daily maximum levels, of NO and NO_2 in the GMR. The greatest decreases appear in the areas near LPS. Consistently, the results show a slight increase in O_3 levels in the areas near LPS, due to the removal of local NO_x emissions from the facility. There is also noticeable decrease in average $PM_{2.5}$ levels.

The implication of these changes will be further explored in future studies. An initial calculation shows that the decrease in average $PM_{2.5}$ only is estimated equivalent to a reduction of approximately 125,000 cars on the road.

In conclusion, the predicted changes in NO, NO_2, O_3 and $PM_{2.5}$ are small across the GMR domain, with a potential for slightly improved air quality at the local and regional scales.

Appendix 1 Conversion of emission rates

The CCAM-CTM air quality model uses the input file containing the emission rate of various species from a source in ppm/min. The emission rate given is in g/s. A conversion is required to run the model.

The factor is determined by using the ideal gas equation

P * V = n * R * T, where

P = pressure [Pa]

V = volume [m^3]

T = temp [K]

n = number [mol]

R is the Boltzmann constant and is equal to 8.31446261815324 [m^3 * Pa ^ K^-1 * mol^-1]

Hence the number of moles of air at standard pressure and temperature (25oC 0r 298oK) in 1 m^3 is

n = P*V/R*T = 101325/8.31/298

The concentration rate in ppm/min of a species is convert to part per second by dividing by 60 and multiplied by 10-6 and then multiplying by the above equation to obtain the number of moles of the species at standard pressure and temperature. That is

Emission rate in ppm/min / 60 x e-6 x 101325/8.31/298 = emission rate in g/s

Or

Emission rate (ppm/min) x 6.8194 x e-7 = emission rate (g/s).

In summary, to convert from ppm-m/min to g/sec, multiply the emission rate of the species by a factor (6.81943e-7). Then the result is multiplied with molecular weight of the species. This is the emission rate in grams per sec per m^2. The EDMS CIT grid cell is 1 km by 1km. Therefore the rate over the grid cell volume at 1m high is 6.8194e-7 x 1e6 or 0.68194.

To convert from g/sec to ppm-m/min, multiply the emission rate (in g/sec per m^2) by 1/(6.81943e-7) and (1/molecular weight). This is the emission rate in ppm-m/min per m^2

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