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Australia’s first national level quantitative environmental justice assessment of industrial air pollution

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Abstract

This study presents the first national level quantitative environmental justice assessment of industrial air pollution in Australia. Specifically, our analysis links the spatial distribution of sites and emissions associated with industrial pollution sources derived from the National Pollution Inventory, to Indigenous status and social disadvantage characteristics of communities derived from Australian Bureau of Statistics indicators. Our results reveal a clear national pattern of environmental injustice based on the locations of industrial pollution sources, as well as volume, and toxicity of air pollution released at these locations. Communities with the highest number of polluting sites, emission volume, and toxicity-weighted air emissions indicate significantly greater proportions of Indigenous population and higher levels of socio-economic disadvantage. The quantities and toxicities of industrial air pollution are particularly higher in communities with the lowest levels of educational attainment and occupational status. These findings emphasize the need for more detailed analysis in specific regions and communities where socially disadvantaged groups are disproportionately impacted by industrial air pollution. Our empirical findings also underscore the growing necessity to incorporate environmental justice considerations in environmental planning and policy-making in Australia.

Keywords: environmental justice, Australia, quantitative, industrial air pollution

1. Introduction

The disproportionate distribution of environmental ‘goods’ and ‘bads’ in relation to the ethnic or socio-economic status of nearby communities has been well-established in the international literature through the use of an environmental justice framework, as previously noted in a special edition of this journal (Stephens 2007). Environmental injustice is defined broadly as the unequal distribution of environmental risks and benefits, with the burden of the risks and the dearth of the benefits falling mainly on racial and/or ethnic minorities, low-income populations, and other socially disadvantaged individuals.

The United Church of Christ’s Commission for Racial Justice (UCC 1987) provided the first comprehensive national level analysis of racial, ethnic and economic inequities in the distribution of environmental hazards in the US. Using zip-code level data, this study found the presence of commercial hazardous waste facilities and uncontrolled waste sites to be significantly associated with a higher percentage of the racial minority population, lower household income and lower housing values across the nation. These findings were investigated and confirmed by numerous studies that

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provided empirical support regarding the widespread practice of locating polluting industries in low-income and non-white neighborhoods (Bullard 1990, Bryant and Mohai 1992, Brown 1995, Mohai *et al*2009b, Schlosberg and Carruthers 2010).

These case studies, and related evidence, led to the implementation of policies at the national, state and local level, including an Executive Order issued by President Clinton in 1994 that required environmental justice concerns to be considered in the decision-making processes for industrial activities that would significantly affect the environment. By 2007, the US Office of Environmental Justice had distributed more than 800 grants to local groups working to improve environmental justice outcomes. These groups started their own pollution assessments to confirm industry emission data through low cost, but certifiable, citizen science activities such as the 'Bucket Brigades' (LABB, no date, Sandler and Pezzullo 2007). In less than three decades, environmental justice has gone from being a fledgling research field to a mainstream and necessary component of US environmental planning and policy.

In significant contrast to the activities in the US, there exists no comprehensive quantitative analysis that draws together these environmental and social justice concerns at the national level in Australia (Arcioni and Mitchell 2005, Byrne and MacCallum 2013, Lloyd-Smith and Bell 2003). This is despite an obvious and growing need for such research to occur, with a number of well-documented sites of massive industrial pollution that have disproportionately affected individuals of lower socio-economic status and Indigenous communities—such as mining and smelting emissions in Mt Isa (Mackay *et al*2013, Munksgaard *et al*2010, Taylor and Schniering 2010) and Port Pirie (EDO 2012, McMichael *et al*1986, Taylor *et al*2013). This is not just an historic issue, since similar concerns are being raised about decisions to locate future toxic sites, such as the planned radioactive waste dump on Aboriginal land at Muckaty Station in the Northern Territory (EJS, no date, Millner 2011).

The analysis herein addresses this research gap by presenting the first national assessment of spatial and social inequalities in the distribution of industrial air pollution in Australia. This research integrates air emissions data from the National Pollutant Inventory (NPI) for the period 2011–2012 with information on the Indigenous status of the population and social disadvantage indices derived from the Australian Bureau of Statistics (ABS) 2011. Our study seeks to determine whether socially disadvantaged populations are disproportionately proximate to industrial air pollution. This approach deliberately mirrors the US methods and analysis that use the Toxic Release Inventory (TRI) and socio-demographic census data, in order to facilitate a consideration of the Australian case alongside existing US studies (Howes 2001). To provide a framework for this national level Australian assessment, we focus on the relationship between the extent of social disadvantage and four specific indicators of industrial air pollution. These include: (a) the presence/absence of NPI sites emitting air pollutants; (b) the number of NPI sites emitting air pollutants; (c) the total volume of air emissions from NPI sites; and (d) the toxicity-weighted volume of air pollution, based on the NPI toxicity rating (NEPC 1999, appendix III), released from NPI sites.

2. Data and methods

2.1. Air pollution data

Air pollution data for this study comes from the most recent set of industry supplied estimates provided to the National Pollution Inventory (NPI 2013). Of the entire set of toxic releases available from the NPI (i.e. to air, water and land), we chose to focus on airborne emissions for two reasons. First, atmospheric emissions represent the majority of all released chemicals in the NPI. Second, emissions to air are most likely to result in actual human exposure and least dependent on human behaviors for exposure to occur (Daniels and Friedman 1999, National Research Council 1991).

The NPI is a joint Commonwealth-State program that has provided open-access estimates of toxic emissions data from government and industrial sources since 2000. Initially the inventory was modeled on the US TRI, although the range of included pollutants was somewhat smaller. The NPI Technical Advisory Panel final report (NEPC 1999) suggested an initial list of 36 substances. It was later expanded to the current list of 90 substances, which remains a significantly smaller number than the 682 on the TRI (TRI 2013).

The NPI allocates a toxicity rating for each chemical based on its impact on human health, its impact on the environment and the risk to its exposure, in order to rank pollutants and select the most important ones for further consideration (NEPC 1999). The downloadable datasheets hosted on the NPI website provide geo-referenced data for each emission of every chemical over a specific threshold, and an estimation of the annual emissions of each of the ranked chemicals. Emissions calculations are made by the polluter using estimation handbooks for each chemical, which are also hosted on the NPI website (NPI 2013). The data for this study included estimations from the year 2011–2012.

2.2. Social disadvantage data

The potential social inequities in the distribution of industrial air pollution were analyzed using a set of variables from the *Census of Population and Housing* (ABS 2011) at the Statistical Area Level 2 (SA2). The SA2s are geographic units with an average population of about 10 000 persons (with a range of 3000–25 000) that cover the entire nation without gaps or overlaps. With these divisions, they aim to, 'represent a community that interacts together socially and economically' (ABS 2013a). To ensure stable estimates for our social disadvantage variables, we excluded 112 SA2s with very small population counts. Our study uses the remaining 2110 SA2 units where the usual resident population is more than, or equal to, 10 persons.

We used five specific measures to capture the multiple dimensions of social disadvantage. As the Indigenous Australian population is one of the most socially disadvantaged groups in Australia (AIHW 2011), we used the percentage of individuals self-identifying as Aboriginal and/or Torres Strait Islander as the first indicator. To measure socio-economic status, an important focus of environmental justice advocacy and research, we relied on the Socio-Economic Indexes for

Table 1. Socio-economic indexes for areas (SEIFA): definitions and interpretations (*Source*: Australian Bureau of Statistics, 2013b.).

Index name	Definition	Interpretation	
		Low score	High score
Index of relative socio-economic disadvantage (IRSD)	Summarizes a range of information about the economic and social conditions of people and households within an area; only measures relative disadvantage.	Relatively greater disadvantage	A relative lack of disadvantage
Index of relative socio-economic advantage and disadvantage (IRSAD)	Summarizes information about the economic and social conditions of people and households within an area, including both relative advantage and disadvantage measures.	Relatively greater disadvantage and a lack of advantage	Relative lack of disadvantage and greater advantage
Index of economic resources (IER)	Focuses on the financial aspects of relative socio-economic advantage and disadvantage, by summarizing variables related to income and wealth.	Relative lack of access to economic resources	Relatively greater access to economic resources
Index of education and occupation (IEO)	Designed to reflect the educational and occupational level of communities.	Relatively lower education and occupation status of people.	Relatively higher education and occupation status of people.

Areas (SEIFA)—a suite of four indexes updated each census by the ABS to rank geographic areas according to their relative socio-economic advantage and disadvantage (ABS 2013b). For each SEIFA index, every SA2 is given a SEIFA score that measures how relatively 'advantaged' or 'disadvantaged' that area is compared with the other areas.

While several specific individual variables (e.g., annual income, poverty rate and median housing value) have been used in the environmental justice research literature to assess the socio-economic status of communities, each SEIFA index represents a summary measure that focuses on one particular dimension of socio-economic disadvantage/advantage and encompasses a range of relevant census variables. The definitions of the SEIFA indexes used in this study are provided in table 1. Each index score is a weighted combination of multiple variables from the 2011 census, and is constructed using principal components analysis (ABS 2013b).

2.3. Methods

To determine how air pollution is related to social disadvantage data on NPI sites and their emission-related attributes were spatially aggregated to each of the 2110 SA2 areas representing our units of analysis. It is also important to factor in the NPI emission sites that are located near the boundaries of the SA2 hosting them. This is often referred to as the 'edge effect problem' in environmental justice research (Bolin *et al*2002, Chakraborty *et al*2011) and occurs when a polluting industry is so close to the edge or boundary of the host census unit that a neighboring (non-host) census unit is also exposed to the air pollution. To address this issue, all NPI sites and emissions located within 1 km of each SA2 boundary were included in the air pollution-related estimates at the SA2 level. Buffer distances of 1 km (note: common practice is to use 1 mile in US studies) have been used in a large number of environmental justice studies to estimate the areal extent of exposure to air pollutants (Baden and Coursey 2002, Bolin *et al*2002, Boone 2002, Chakraborty and Armstrong 1997, Glickman 1994, Kearney and Kiros 2009, Maantay 2007, Mennis and Jordan 2005, Mohai *et al*2009a, Neumann *et al*1998, Walker *et al*2005).

Our statistical analysis comprised of three phases. We first examined the presence or absence of sites that report air pollution emissions of the most toxic 90 chemicals (the identified top ranked toxic pollutants in the NPI), asking whether there are differences in the social disadvantage characteristics of populations in communities at the SA2 level that contain these sites, compared to those that did not. This basic approach has been applied in several influential and widely-cited environmental justice studies conducted at the national level in the US (Anderton *et al*1994, Been 1995, Goldman and Fitton 1994, Hird 1993, UCC 1987, 2007).

While the presence of a polluting site in a community has some validity as an indicator of environmental pollution, its presence may not be a reliable indicator of the quality and quantity of the pollution burden. Therefore, we proceeded to carry out a more detailed analysis that focused on the magnitude of air pollution released in each SA2 based on three indicators that have been used in previous environmental justice research: the total number of NPI sites, total volume of air pollution emissions, and toxicity-weighted volume of air emissions.

The second phase of analysis explored the relationship between social disadvantage and the magnitude of air pollution

Table 2. Social disadvantage characteristics of communities with and without NPI sites.

Variable	National average	SA2s without NPI sites	SA2s with NPI sites	Diff	t-test: p-value
Percent indigenous	3.86%	2.58%	4.37%	−1.79%	<0.001
Index of relative socio-economic disadvantage (IRSD)	998.27	1019.82	990.92	28.90	<0.001
Index of relative socio-economic advantage and disadvantage (IRSAD)	998.66	1027.52	986.76	40.76	<0.001
Index of economic resources (IER)	999.09	1019.82	990.92	28.89	<0.001
Index of education and occupation (IEO)	997.80	1029.61	985.24	44.38	<0.001
Number of SA2s (n)	2110	1513	597		

at the community level, using descriptive statistical measures. More specifically, the mean values of each social disadvantage variable were examined with respect to the three indicators of air pollution, based on the classification of SA2 units into four quartiles. Prior environmental justice studies have used a similar approach to group census areas into terciles (Pastor *et al*2005), quartiles (Chakraborty 2009), or quintiles (Linder *et al*2008), based on the degree of potential risk from air pollutants, and compared their socio-demographic characteristics.

Our third and final phase of the analysis focused on evaluating social disadvantage measures in the most polluted communities through the application of a method that has been employed to measure disproportionate exposure to hazardous air pollutants in the US (Apelberg *et al*2005, Collins *et al*2011, Linder *et al*2008). Specifically, we evaluated the statistical significance of differences in the proportion of the most polluted SA2s (ranked above the 90th percentile based on the NPI air pollution indicators) across quartiles of our five measures of social disadvantage using z-tests for proportions. This involves subdividing all SA2s into four quartiles based on each measure of social disadvantage and calculating the percentage of SA2s in each quartile that are 'most polluted'—defined as the top 10% among all SA2 in terms of each of the three NPI air pollution indicators previously mentioned.

We used z-tests to analyze differences in proportions between the reference quartile and each of the other three quartiles. The presence of pollution-related social disparities appears as a statistically significant change in the proportion of 'most polluted' SA2 areas, going from the lowest-to-highest quartile for the Indigenous percentage and highest-to-lowest quartile for the four SEIFA indexes. We estimated relative risks (RR), p-values, and 95% confidence intervals (CI) for being 'most polluted' across quartiles of our social disadvantage measures, following previous environmental justice studies using the 90th percentile approach (Apelberg *et al*2005, Collins *et al*2011, Linder *et al*2008).

While more sophisticated multivariate analysis techniques (e.g., spatial autoregressive models) have been used in environmental justice research to explore the statistical effects of specific variables such as annual income or poverty rate, the relative risk technique employed here best allows us to examine and compare multiple dimensions (i.e. the SEIFA indexes) of social disadvantage with respect to the national indicators of air pollutant emissions.

3. Results

3.1. Communities with and without polluting industries

The first phase of our analysis examined differences between SA2 areas that host NPI sites reporting air releases (inside or within 1 km of their boundaries) and those areas that do not host such sites, based on the mean values of the social disadvantage variables. The results are summarized in table 2.

For all of the social disadvantage variables, the difference in group means (host versus non-host) is statistically significant and consistent with our expectations regarding environmental and social injustices in the distribution of air pollution. Compared to non-host areas, the mean percentage of Indigenous individuals is almost 1.7 times higher in SA2 units hosting NPI air pollution sites. The mean scores of the four SEIFA indexes are significantly higher in non-host areas, with the IEO indicating the largest difference. This suggests that communities with relatively greater socio-economic disadvantage, and lower access to economic resources, and those with lower levels of education and occupational status in particular, are more likely to host NPI sites.

3.2. Comparison of means by pollution quartile

The next phase of the analysis explored the independent effect of each social disadvantage measure on the magnitude of air pollution across SA2s. The average value of each variable for the quartiles associated with each pollution indicator are provided in table 3, along with the statistical significance of the linear trend across the five levels of pollution (zero and four quartiles).

Regardless of how air pollution is quantified, the mean percentage of Indigenous individuals increases gradually from the least polluted (zero or bottom 25%) to the moderately polluted quartiles, and rises substantially in the most polluted quartile (top 25%). When compared to communities without NPI sites, the Indigenous percentage is about 2.4 times higher in communities falling in the highest quartile of emissions

Table 3. Means of social disadvantage variables by magnitude of air pollution from NPI sites.

	SA2s without NPI sites ($n = 597$)	Quartile means: SA2s with NPI sites ($n = 1513$) 1st	2nd	3rd	4th	Trend[a] p-value
Number of sites						
Percent indigenous	2.58%	3.80%	4.51%	4.08%	5.31%	0.001
IRSD	1019.82	997.98	1004.42	992.21	969.11	<0.001
IRSAD	1027.52	1003.17	1002.95	982.30	959.41	<0.001
IER	1019.82	1003.72	1003.62	985.39	961.99	<0.001
IEO	1029.61	1007.16	999.76	976.83	958.17	<0.001
Emission volume						
Percent indigenous	2.58%	3.20%	2.76%	5.26%	6.25%	<0.001
IRSD	1019.82	1001.09	1002.37	983.81	976.44	<0.001
IRSAD	1027.52	1007.86	1000.66	980.30	958.32	<0.001
IER	1019.82	1009.51	1002.90	980.62	961.39	<0.001
IEO	1029.61	1011.85	997.15	981.79	950.23	<0.001
Toxicity-weighted emissions						
Percent indigenous	2.58%	3.42%	2.38%	4.55%	7.12%	<0.001
IRSD	1019.82	999.31	1004.52	986.52	973.45	<0.001
IRSAD	1027.52	1003.13	1005.85	980.94	957.33	<0.001
IER	1019.82	1005.57	1007.32	981.81	959.85	<0.001
IEO	1029.61	1004.67	1003.31	982.67	950.40	<0.001

[a] Tests for trend based on linear regression with the NPI pollution quartiles as a categorical variable.

volume, and 2.8 times higher for those in the highest quartile of emissions toxicity.

This pattern of change with respect to increasing pollution levels is also evident from the SEIFA index results. The mean scores for all four variables indicate a steady and sharp decline from the least polluted to most polluted quartile, with the index of relative socio-economic disadvantage (IRSAD) and the index of education and occupation (IEO) showing the largest decreases (where lower numbers for each index indicate significant disadvantage).

These results show that communities in the highest quartile for our pollution indicators are characterized by significantly greater socio-economic disadvantage and very low levels of education and occupation status, compared to those in the other pollution quartiles or communities without NPI sites.

3.3. Social disadvantage in the most polluted communities

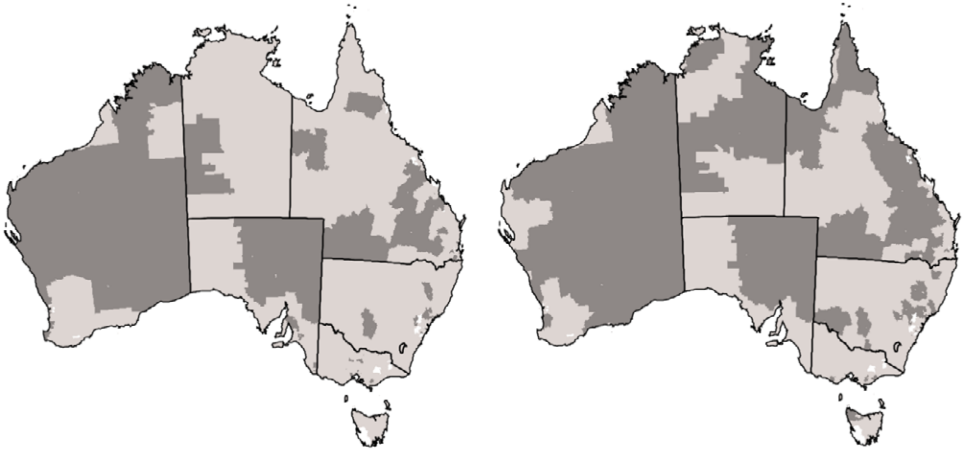
The final phase of our analysis focuses on communities where the magnitude of air pollution, as measured by our three indicators, is at or above the top 10% among all SA2 areas. For each of our three air pollution indicators, the top 10% ($n = 151$) comprises SA2s with at least nine sites, with a total of 2.1 Mt of emissions, and 17.7 Mt of toxicity-weighted emissions respectively, within 1 km of their boundaries.

Figure 1 depicts the distribution of these SA2s in the top 10% for each air pollution indicator, which we refer to here as the 'most polluted' communities. The most polluted areas are the majority of the state of Western Australia, the Gulf country in the Northern Territory and Queensland, Cape York and mid coastal Queensland, and northeastern South Australia.

Figure 1 demonstrates how the location patterns of SA2s in the 'most polluted' category differ according to the pollution indicator used. In Queensland, in particular, several SA2 areas, such as those on Cape York and the Gulf country, that are in the bottom 90% for the number of NPI sites fall in the top 10% for emission volume and toxicity-weighed emissions. These results are repeated in all the other States and the Northern Territory to a lesser degree.

The findings from our analysis of social disadvantage measures by quartile for the three definitions of 'most polluted' communities are summarized in table 4.

Consider the first set of quartiles associated with the Indigenous variable at the top of this table (number of NPI sites). Each quartile includes about 528 SA2 units, with the lowest quartile containing the smallest percentage of the Indigenous population (0.67% or lower) and the highest quartile containing the largest Indigenous percentage (3.37% or higher). A proportional distribution of the most polluted (top 10%) communities implies that approximately 38 of these 151 SA2s should appear in each quartile. However, the most polluted SA2s, based on the number of NPI sites, occur disproportionately in the highest quartile of the Indigenous population. Communities with the highest percentage of Indigenous individuals are about 1.5 times more likely to be among the most polluted areas compared to those with the lowest Indigenous percentage, as indicated by the risk ratio. This difference is also statistically significant ($p < 0.05$), when the number of NPI sites are considered. This ratio, and


(a) Number of NPI sites

(b) Total emission volume

(c) Toxicity-weighted emission volume

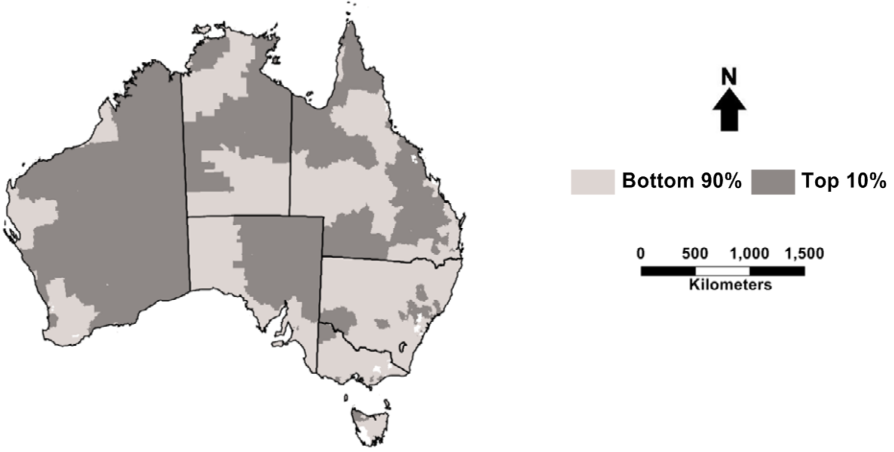


Figure 1. Communities falling at, or above, the 90th percentile for NPI air pollution. (a) Number of NPI sites. (b) Total emission volume. (c) Toxicity-weighted emission volume.

the significance of the disparity, increases substantially when emission volumes and toxicity are examined. Communities in the highest quartile for Indigenous percentages are 7.8 (emission volume) and 6.7 (toxicity-weighted volume) times more likely, respectively, to belong to the most polluted category compared to those in the lowest quartile for this variable.

Our results reveal similar patterns for the SEIFA indexes, the next set of variables appearing in table 4. Since the environmental justice literature suggests that individuals of higher socio-economic status generally experience decreased exposure to environmental pollution compared to those of lower socio-economic status, we expected relatively fewer SA2s in the 'most polluted' category to correspond with higher levels of socio-economic advantage. Therefore, we treated the quartile with the highest score for each SEIFA index as the reference quartile in this analysis. Communities with the lowest values of IRSD (greatest disadvantage) are 8.1 times more likely to be among the most polluted communities compared to those with the highest values of IRSD (least disadvantage), based on the number of NPI sites. Similar results and ratios are observed for the other SEIFA indexes for this pollution indicator.

When emission volumes and their toxicity are considered, a clear inverse relationship emerges between a community's socio-economic advantage and its chances of belonging to the 'most polluted' category. Communities with the lowest values (first quartile) for both the IRSD and index of relative socio-economic advantage and disadvantage (IRSAD) are about six times more likely to belong to the most polluted category than those with the highest values (fourth quartile) for these indexes. While this ratio is smallest for the index of economic resources (IER) (<2.0), the IEO indicates the greatest disparity among the SEIFA indexes. The chances of falling in the most polluted category for SA2 units in the lowest quartile of the IEO are about 13.2 times (emission volume) and 10.4 times (toxicity-weighted emissions) greater than those in the highest quartile for this index.

4. Discussion

This letter contributes to the environmental justice literature by assessing the relationship between social disadvantage and industrial air pollution in Australia, a country where quantitative environmental justice analysis had not been previously conducted at the national scale. Our findings suggest that

Table 4. Percent of communities at or above the 90th percentile (top 10%) of NPI pollution and relative risk (RR) by social disadvantage characteristics.

	No. of SA2s in top 10%	Percent of SA2s in top 10%	RR	95% CI Lower	95% CI Upper	*p*-value
		Number of sites				
Percent indigenous						
Q1	34	6.5%	—			
Q2	36	6.8%	1.06	0.67	1.66	0.811
Q3	40	7.6%	1.17	0.76	1.83	0.475
Q4	52	9.9%	1.53	1.00	2.32	0.045
Index of relative socio-economic disadvantage						
Q1	57	10.8%	8.14	3.75	17.69	<0.001
Q2	66	12.5%	9.43	4.37	20.36	<0.001
Q3	32	6.1%	4.57	2.04	10.26	<0.001
Q4	7	1.3%	—			
Index of relative socio-economic advantage and disadvantage						
Q1	66	12.5%	9.43	4.37	20.36	<0.001
Q2	56	10.6%	8.00	3.68	17.39	<0.001
Q3	33	6.3%	4.71	2.10	10.56	<0.001
Q4	7	1.3%	—			
Index of economic resources						
Q1	63	12.0%	4.85	2.70	8.70	<0.001
Q2	39	7.4%	2.99	1.62	5.54	<0.001
Q3	47	8.9%	3.61	1.98	6.59	<0.001
Q4	13	2.5%	—			
Index of education and occupation						
Q1	62	11.8%	7.75	3.75	16.02	<0.001
Q2	61	11.6%	7.63	3.69	15.78	<0.001
Q3	31	5.9%	3.87	1.79	8.34	<0.001
Q4	8	1.5%	—			
		Emission volume				
Percent indigenous						
Q1	10	1.9%	—			
Q2	16	3.0%	1.60	0.73	3.49	0.240
Q3	47	8.9%	4.69	2.40	9.18	<0.001
Q4	78	14.8%	7.80	4.08	14.90	<0.002
Index of relative socio-economic disadvantage						
Q1	62	11.8%	6.89	3.46	13.72	<0.001
Q2	54	10.3%	6.00	2.99	12.03	<0.001
Q3	26	4.9%	2.89	1.37	6.11	0.006
Q4	9	1.7%	—			
Index of relative socio-economic advantage and disadvantage						
Q1	62	11.8%	5.64	3.00	10.58	<0.001
Q2	53	10.1%	4.82	2.55	9.12	<0.001
Q3	25	4.8%	2.27	1.13	4.57	0.021
Q4	11	2.1%	—			
Index of economic resources						
Q1	51	9.7%	2.68	1.61	4.48	<0.001
Q2	40	7.6%	2.10	1.23	3.58	0.006
Q3	41	7.8%	2.15	1.27	3.66	0.005
Q4	19	3.6%	—			
Index of education and occupation						
Q1	79	15.0%	13.17	5.79	29.93	<0.001
Q2	49	9.3%	8.17	3.53	18.90	<0.001

Table 4. (Continued.)

	No. of SA2s in top 10%	Percent of SA2s in top 10%	RR	95% CI Lower	95% CI Upper	*p*-value
Q3	17	3.2%	2.83	1.12	7.12	0.027
Q4	6	1.1%	—			
		Toxicity-weighted emissions				
Percent indigenous						
Q1	11	2.1%	—			
Q2	18	3.4%	1.63	0.78	3.42	0.194
Q3	48	9.1%	4.36	2.29	8.29	<0.001
Q4	74	14.0%	6.73	3.61	12.53	<0.001
Index of relative socio-economic disadvantage						
Q1	57	10.8%	6.33	3.17	12.66	<0.001
Q2	55	10.5%	6.11	3.05	12.24	<0.001
Q3	30	5.7%	3.33	1.60	6.95	0.001
Q4	9	1.7%	—			
Index of relative socio-economic advantage and disadvantage						
Q1	59	11.2%	5.36	2.85	10.09	<0.001
Q2	51	9.7%	4.64	2.44	8.80	<0.001
Q3	30	5.7%	2.73	1.38	5.38	0.004
Q4	11	2.1%	—			
Index of economic resources						
Q1	50	9.5%	2.50	1.51	4.14	<0.001
Q2	38	7.2%	1.90	1.12	3.21	0.018
Q3	43	8.2%	2.15	1.28	3.60	0.004
Q4	20	3.8%	—			
Index of education and occupation						
Q1	73	13.9%	10.43	4.85	22.43	<0.001
Q2	51	9.7%	7.29	3.34	15.91	<0.001
Q3	20	3.8%	2.85	1.22	6.69	0.016
Q4	7	1.3%	—			

the presence of Indigenous and socio-economically disadvantaged populations plays a persistent role in the distribution of industrial sites emitting significant air pollution, as well as the quantity and toxicity of air emissions from these sites.

In terms of site location, we found communities hosting industrial pollution sources contained significantly higher proportions of Indigenous populations, had relatively greater socio-economic disadvantage, limited access to economic resources, and lower levels of education and occupation status, when compared to communities where these sites are absent. With respect to our remaining pollution indicators, we found communities with the highest frequency, volume, and toxicity of emissions to have significantly greater percentages of the Indigenous population and higher levels of socio-economic disadvantage. The quantities and toxicities of industrial air pollution are particularly high in communities with the lowest levels of educational attainment and occupational status, as demonstrated by the IEO. This implies that areas with more people employed in low-skilled occupations, or unemployed, are most likely to host NPI sites releasing the highest volumes of the most toxic chemicals.

There are several limitations associated with the industrial pollution data used in this study. As documented elsewhere, there are ongoing difficulties in developing and using emission estimation techniques as outlined in the TAP final report (NEPC 1999) and in subsequent annual NEPC reports that provide feedback on the NPI. The most recent report (2011–12) also notes that the lack of reliable industry compliance is an ongoing concern (NEPC 2011, p 67). In addition, this report noted that NPI emission estimation technique manuals needed to be updated to reflect Australian conditions, and that there was a need for aggregated emission data to be updated on the website (NEPC 2011, p 67).

Although the specific methodology and approach used in this analysis was guided by the toxicology rankings, we are aware of the significant constraints on attempting to reconcile or compare the ‘toxicity’ of various chemicals and even more so when weighted by their emission volume. However, in conducting this study we applied established, standard practices in an effort to reduce any potential problems, and to allow as much transferability of method between the Australian case and US analyses. Even with these limitations, this assessment has provided strong empirical evidence of quantitative environmental injustice at the national scale that needs to be addressed by policy-makers.

This national level quantitative assessment of environmental justice has found significant and systemic inequities in the social distribution of industrial air pollution in Australia. Regardless of how air pollution was measured; facility presence, emission volume, or toxicity, our analysis indicated a consistent and disproportionate impact on Indigenous and socially disadvantaged communities. These quantitative results demonstrate social inequities that are consistent with those found in the US using the equivalent TRI pollution data. These findings support the ad hoc qualitative case studies carried out around the country that detail finer-scale air pollution-related injustices. Consequently, we believe that the issue of environmental justice requires consideration by Australia's environmental law and policy-makers. Our findings demonstrate that efforts to address or mitigate environmental injustice in Australia must include policies that seek to reduce chronic air pollution from industrial activities.

In the US, the environmental justice framework has expanded in recent years to include issues which are not directly related to the distribution of environmental 'bads'. Research has progressed in this respect in the Indigenous space especially (Figueroa 2006, 2011, Whyte 2013). Indigenous cultural links between their community's (and each individual's) connection to traditional lands and associated struggles for genuine recognition of ownership greatly inform this developing research field internationally, and to a more limited degree, in Australia (Robertson *et al*2012).

Finally, it is important to consider that this case study focused on assessing the current patterns of industrial air pollution in Australia, and not the processes that led to the observed social disparities. The results cannot be used to determine whether communities with NPI sites contained a disproportionate number of Indigenous or socio-economically disadvantaged populations at the time the location decisions were made, or whether subsequent events caused the inequities reported in this analysis. More research is necessary to identify the specific historical trajectories of industrial and economic development, the role of local factors such as zoning, land-use restrictions, land values, and labor availability, as well as other political, social, and spatial processes that are potentially responsible for the inequitable distribution of industrial air pollution sources. While these findings illustrate the distributional inequity, there is more to fully understanding environmental injustice in Australian Indigenous communities, as a consequence, much more analysis in this space needs to be conducted. Although our study does not explicate the processes leading to the current disparities, the results represent an important starting point for more detailed and longitudinal investigation of the causes and consequences of injustice in specific regions and communities where socially disadvantaged residents are disproportionately impacted by industrial air emissions.

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