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Pollutant loads from coal mining in Australia: Discerning trends from the National Pollutant Inventory (NPI)

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ABSTRACT

A key environmental concern is pollution loads released from human activity, since excessive pollutant loads can cause significant public health and/or environmental impacts. A principal objective of environmental regulation is therefore to minimise pollutant releases. The most common approach to assessing and monitoring pollutant loads is through pollutant release databases, with such systems now operating throughout Europe, North America and Australia. This paper has compiled and analysed an extensive data set on Australian coal mining and associated pollutant emissions reported through the National Pollutant Inventory (NPI). In Australia, the coal industry has been growing rapidly over recent decades, and this is causing significant community concerns over cumulative environmental impacts. The pollutant loads and intensities from coal mining are analysed in conjunction with production data. The trends identified in this paper provide an important basis to understand the value of pollutant release and transfer registers, such as the NPI, and demonstrate the critical need to integrate such data with ongoing trends in industry and environmental management initiatives.

1. Introduction

A key environmental concern is pollution loads released from human activity, since excessive pollutant loads can cause significant public health and/or environmental impacts, such as cancer, biodiversity loss, water or air quality degradation and loss of ecological integrity. A principal objective of environmental regulation is therefore to minimise pollutant releases to levels within the carrying capacity of the local environment and thereby protect ecosystems and/or public health. An increasingly popular approach to assessing and monitoring pollutant loads is through pollutant release databases, with such systems now operating throughout Europe, North America and Australia.

In Australia, the National Pollutant Inventory (NPI) compiles estimates on direct pollutant emissions from major industrial facilities as well as diffuse emissions from small facilities, households, transport or other sources. Large facilities report emissions based on thresholds for the 93 NPI-listed pollutants, with emissions based on direct monitoring or estimated based on inputs or other methods. The first year of reporting was the 1998/99 financial year, giving a decade of pollutant release data. Studies analysing NPI data, however, appear to be very rare.

One issue of national significance to Australia is the pollutant loading associated with coal mining. The second biggest export industry for Australia is black coal, with exports in 2010 being 300.3 Mt earning $42.78 billion, while iron ore exports were 401.8 Mt earning $47.13 billion (with a further $1.4 billion earned from iron and steel exports) (ABARES, 2011).

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Australia is also the world's largest coal exporter, and combined with strong growth plans for the sector, this gives rise to a strong imperative to understand the pollutant loads associated with coal mining.

This paper presents the results of a study combining coal production trends and NPI pollutant release data for coal mines in Australia, assessing trends in pollutant loads as well as the intensity of unit pollutant loads per tonne of saleable coal. By combining both loads and intensities, a valuable picture can be developed for investigating pollution loads associated with coal mining – an important area in addition to issues such as greenhouse gas emissions from coal combustion. Given the expected growth in Australian coal production, exports and use, as well as the current and future global importance of coal in primary energy supply, the paper presents a unique case study of clear relevance for environmental policy worldwide.

2. Background – Pollutant Inventory systems

2.1. *History and overview*

A key sustainability challenge is to reduce both pollution loads and pollution intensity. For example, sulfur dioxide (SO_2) emissions from coal-fired electricity leads to acid rain problems – as electricity generation grows, there is a need to significantly reduce the intensity of SO_2 emissions to ensure that total emissions do not overwhelm environmental capacity. Other pollutants from electricity generation include particulate matter, nitrogen oxides (mainly as NO_x), carbon monoxide and heavy metals such as selenium and mercury. Since the 1970s and the rise of environmental legislation and controls in countries, such as the USA and Australia, power stations have installed pollution control equipment such as scrubbers and electrostatic precipitators (e.g. MIT, 2007) to meet environmental standards, as shown in Fig. 1.

However, given the continuing growth in population, industry and consumption, especially in rapidly developing countries like China and India (without forgetting other populated regions of the world), the problem of pollution burdens remains a major global sustainability challenge (e.g. air quality issues in urban or industrial areas) (e.g. MIT, 2007; USEPA, 2008; Shealy & Dorian, 2010).

A 'Pollutant Release and Transfer Register' (PRTR) (Wexler & Harjula, 2005) is a database containing estimated pollutant release data submitted by companies to government and available to the general public. The concept of a PRTR was first developed in the USA and Canada after the Bhopal disaster in India in 1984 saw thousands of people die from methyl isocyanate exposure and a sister plant in Virginia, USA, had a serious chemical release shortly after Bhopal (Wexler & Harjula, 2005; USEPA, 2011). The Toxics Release Inventory (TRI) Program was established in 1990 in the USA, becoming the first public PRTR, and the Canadian National Pollutant Release Inventory (NPRI) formed in 1994. Following in the steps of America and Canada, Australia developed their own PRTR by forming the National Pollutant Inventory (NPI) in 1998.

In general, a PRTR uses a combination of inputs (e.g. fuel, chemicals), direct facility emissions, facility transfers and/or diffuse emissions to identify and estimate land, water and air emissions generated by industry practices and facilities. A detailed critique and synthesis of the current state of PRTRs is given by Burritt & Saka (2006).

Data from PRTR programs are intended to provide the basis to examine pollution burdens and trends over time. Furthermore, PRTR data can be linked to formal life cycle impact assessment studies (e.g. Althaus & Classen, 2005), cleaner production initiatives or sustainability metrics (e.g. Diniz Da Costa & Pagan, 2006). Although the TRI, NPRI and NPI programs have been running for up to 20 years, very few rigorous studies of PRTR data, especially trends over time, appear to have been published. With respect to sustainability, PRTR data are crucial and should help inform progress on significant problems such as pollution burdens.

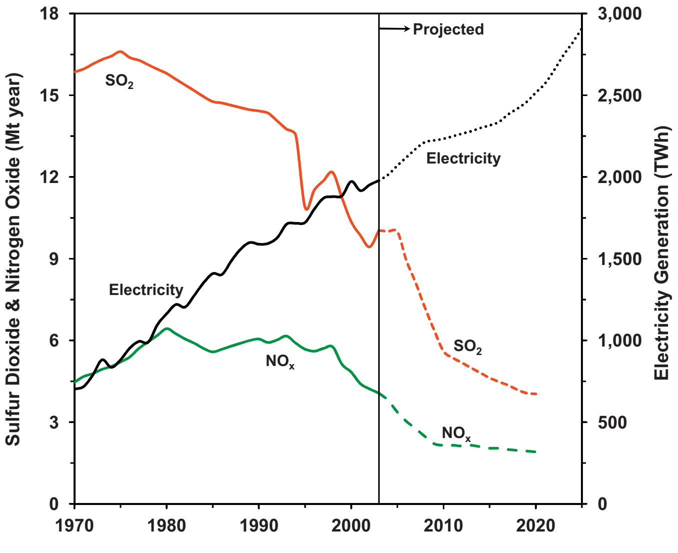

Fig. 1 – Electricity generation and air pollution load trends in the USA. (Redrawn from MIT, 2007.)

2.2. *Pollutants from coal mining*

Coal can be extracted either by open cut or underground mining techniques, depending on coal seam depth, geotechnical conditions, land use constraints or other factors. The most common method for open cut mining is draglines or excavators and haul trucks, while underground mining includes longwall, bord and pillar or other methods. Some coal projects may have an open cut mine combined with underground extensions to access deeper coal.

In general, there are three major sources of pollutants from coal mining – emissions from heavy machinery (i.e. diesel combustion), dust and particulate emissions from exposed mine workings and mine waste (overburden or waste rock, plus potentially tailings dams), and dissolved pollutants in mine site waters. Gaseous emissions can include sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO) and fine particulate matter at sizes as low as 10 μm or even 2.5 μm (known as PM_{10} or $PM_{2.5}$). The principal environmental impacts from SO_2 are acid rain, smog from NO_x and visibility and respiratory issues from particulate matter. Furthermore, dust and particulate matter can also contain pollutants themselves, in particular heavy metals which can lead to additional impacts when inhaled or ingested. Dissolved pollutants in mine site waters can cause impacts on biodiversity and water quality if they are released into adjacent freshwater ecosystems or groundwater. Overall, it is important to assess the load of a particular pollutant, its pathway into the environment (land, air, water), potential receptors as well as possible environmental and public health impacts.

A variety of methods have been developed to address these pollutant risks in coal mining. Dust and particulate matter releases can be minimised through an active watering program of roads and surfaces, which is often combined with careful mine planning and operations. The SO_2, NO_x and CO emissions are minimised through good maintenance of heavy machinery, modern engines with pollution control technology (e.g. catalytic converters) as well as stringent fuel quality standards (e.g. maximum sulfur levels in diesel; see DSEWPC, 2011).

The principal approach used by the NPI to estimate pollutant loads from mining is through the use of a formula which includes the emissions factor for a particular activity, control efficiency, and the rate and hours of that activity. The general formula is therefore (NPI, 2001):

$$\text{Pollutant Load} = [\text{Activity Rate} \times \text{Operating Hours} \times \text{Emissions Factor} \times (1 - \text{CE}/100)] \qquad [1]$$

where CE is control efficiency (in percent). This gives the annual release of a pollutant, such as dust, normally in kilograms per year (kg/year). For coal mining, a range of emissions factors are applied for various activities, such as draglines, excavators, haul trucks and so on, taking into account moisture content, mean wind speed, vehicles speed and others (see Table 1 on pages 11–12, NPI, 2001). To estimate metal emissions, the concentrations in dust are multiplied by the annual dust or particulates load, to give the load of a particular metal in kg/year.

2.3. *Emissions and environmental standards*

In general, there are no national regulatory standards in Australia which specifically limit the loads of a particular pollutant being emitted to the environment, although most states have standards for particular sources such as vehicles or certain facilities. Commonly the average ambient concentrations are monitored and this is used as the basis for assessing environmental quality or public health. In essence, this implies that a given pollutant load can be arguably acceptable as long as it does not lead to exceedance of regulatory concentrations for that segment of the environment (e.g. water, air, soil, biota).

In Australia, ambient air quality standards are set nationally through a National Environment Protection Measure (NEPM) which was originally approved in June 1998 and amended in July 2003 to include $PM_{2.5}$ (EPHC, 2003). For example, the standard for average daily PM_{10} and $PM_{2.5}$ in air quality is 50 and 25 $\mu g/m^3$. Water quality standards are regulated through the National Water Quality Management Strategy (NWQMS), which sets a risk management framework based on an ecotoxicological approach for pollutants in fresh or marine waters (ANZECC & ARMCANZ, 2000). For example, the allowable concentration depends on the desired conservation status for the biodiversity of the ecosystem, with allowable copper (Cu) concentrations ranging from 1.0, 1.4 to 1.8 μg/L to protect 99, 95 and 90% of aquatic species, respectively. In effect, such concentration limits significantly constrain loads to an environmental segment, with major inputs leading to risks of exceedance. Soil quality standards are mainly set in relation to contaminated sites through a NEPM (see NEPC, 1999), with guidelines on sediment quality in freshwater and marine ecosystems provided by the NWQMS.

3. Methodology

The primary methodology adopted for this study was the preparation and combination of respective data sets on coal production and annual pollutant releases. From this data, unit metrics or pollutant intensity were calculated, i.e. mass of pollutant per tonne of saleable coal. These data were analysed over the time period of the NPI, specifically from 1998/99 to 2009/10. The pollutant intensities were estimated for the states of New South Wales (NSW), Queensland (QLD), South Australia (SA), Tasmania (TAS) and Western Australia (WA) and for national levels (no coal mining occurs in the Northern Territory). To compare values obtained from individual mines and examine a major field in detail, a comprehensive case study of the Hunter Valley coal province, NSW was also conducted. Since the Victorian lignite (brown coal) mines are integrated with adjacent power station complexes, it was not possible to assign pollutant releases between mining and power generation.

A total of 11 primary air and heavy metal and metalloid pollutants were selected, namely NO_x, SO_2, CO, PM_{10}, VOCs, As, Cu, Hg, Pb, Se and Zn. These are based on the quantity of pollutants released, the potential severity of environmental or public health impacts and common pollutants found in coal mining (see Lockwood et al., 2009). Common environmental

Table 1 – Australian cumulative and annual coal production by state (including coal type) (all Mt) (data updated from Mudd, 2009).

	Queensland	New South Wales	Victoria[a]	Tasmania	South Australia	Western Australia
Coal type	Bituminous, sub-bituminous	Bituminous, sub-bituminous	Lignite	Bituminous	Sub-bituminous	Sub-bituminous
Cumulative production	4552.8	4982.8	2261.2	28.1	123.6	213.5
2010 production[b]	253.7	185.7	~68.5	~0.6	~3.8	~6.6

[a] Victoria also includes a minor historical production of 22.7 Mt black coal, with very small but uneconomic resources remaining.
[b] 2010 data are preliminary only.

and health impacts from these pollutants are included in supplementary material (Table S1). Although particulate matter less than 2.5 μm ($PM_{2.5}$) is now required by NPI reporting, this was only required from the 2007/08 reporting year and is thus not included in this study due to only three years of data being available.

All results are presented in tabular and graphical forms for all states and Australia, with additional figures and a table for the Hunter Valley coal mines (including mine type). For the figures, the main line is the Australian pollutant intensity average, while the minimum and maximum error bars are the respective state average pollutant intensity. The year 1998/99 only has 19 mines reporting, compared with 114 mines at the time (including 3 associated with power stations in Victoria), and the data represent, therefore, only a minority of Australian coal mining operations. By 2010, the total number of coal mines in Australia was about 120, meaning almost all reported to the NPI. As such, all graphs are indexed relative to 1999/00 to show relative change over time. In the tables, the historical trend of pollutant intensity is compared with the pollutant intensity of 1999/00, and a relative change of greater than +5% is classified as an increase (I), more than −5% change is a decrease (D) while ±5% is considered constant (C).

All state and national coal production data are adapted from Mudd (2009), Mohr (2010), NSWDPI (2009) and ABARES (2011). Annual pollutant release data are obtained from the NPI online database (www.npi.gov.au) (NPI, 2011), which in turn obtains its data from statutory reports submitted annually from industrial facilities across Australia which trigger the NPI reporting thresholds. For mining, emissions are estimated by applying the methods from the NPI manual for mining (NPI, 2001). It is assumed that all data reported to the NPI are an accurate reflection of the estimation methods.

4. Results

4.1. *Australian coal production*

Coal was the first mineral commodity to be mined in Australia, beginning in the late 1790s near Sydney in New South Wales (Mudd, 2009). Annual production remained relatively minor and local until the late 1800s when modest scale coal mining had also been initiated in other states. From the 1950s, the Australian coal industry began a major expansion, led by New South Wales and Queensland and the start of large scale open cut mining. Approximately 80% of all coal in Australia is produced by open cut mining (Mudd, 2009). The coal production by state, including major coal type, cumulative and recent annual production, is given in Table 1. Production, exports and overburden over time are shown in Fig. 2.

4.2. *Australian and state pollutant intensities and trends*

National pollutant loads over time are given in Table 2 (full pollutant loads of states provided in supplementary tables). In general, although not all coal mines are reporting in the early years (especially 1998/99), the increasing loads over the 2000s are when most (if not all) mines report – meaning that the loads cannot simply be a function of more mines reporting. Furthermore, over the 2000s, annual coal production has increased from 300 Mt in 1999 to 445 Mt in 2009, suggesting that the increases in loads are more closely related to production levels than reporting. This is further examined in the pollutant intensity indices. Curiously, Tasmania is commonly missing from NPI data, presumably due to its very small scale (~0.6 Mt/year) not triggering reporting thresholds.

The national and state average pollutant intensities and trends over time are summarised in Table 3. The indices of pollutant intensity over time for heavy metals from Australian coal production are shown in Fig. 3.

The national averages of most metals have shown continuous increases since 2000/01, while minimum and maximum state indices appear to show no clear trend and often wide variation. Zn shows consistent growth and achieved an almost 60-fold increase from the 1999/00 intensity. Furthermore, Se releases showed the most significant variation in state averages, with a 100-fold increase in maximum state indices compared to a 20-fold increase in the national index. Cu and Hg have shown similar strong increasing tends. In contrast, the slight increases in the indices for As and Pb are less dramatic and show minor variation over time, although the maximum state index for Pb does increase 4-fold in recent years.

Fig. 4 illustrates the indices of air emissions from Australian coal mining. Similar to metals, 4 out of 5 air pollutants showed a continuous increase. VOCs had the most significant 9-fold increase by 2009/10. SO_2 intensity increased steadily until 2005/06, but then declined dramatically by 2009/10 to 60% of the 1999/00 level. This result is correlated with the implementation of the *Fuel Quality Standards Act* 2000, the Fuel Quality Standards Regulations 2001 and the Fuel Standard (Automotive Diesel) Determination 2001, which has significantly reduced the maximum sulfur content of diesel fuel from 500 parts per million (ppm) in December 2002, 50 ppm from January 2006 and 10 ppm from January 2009 (DSEWPC, 2011).

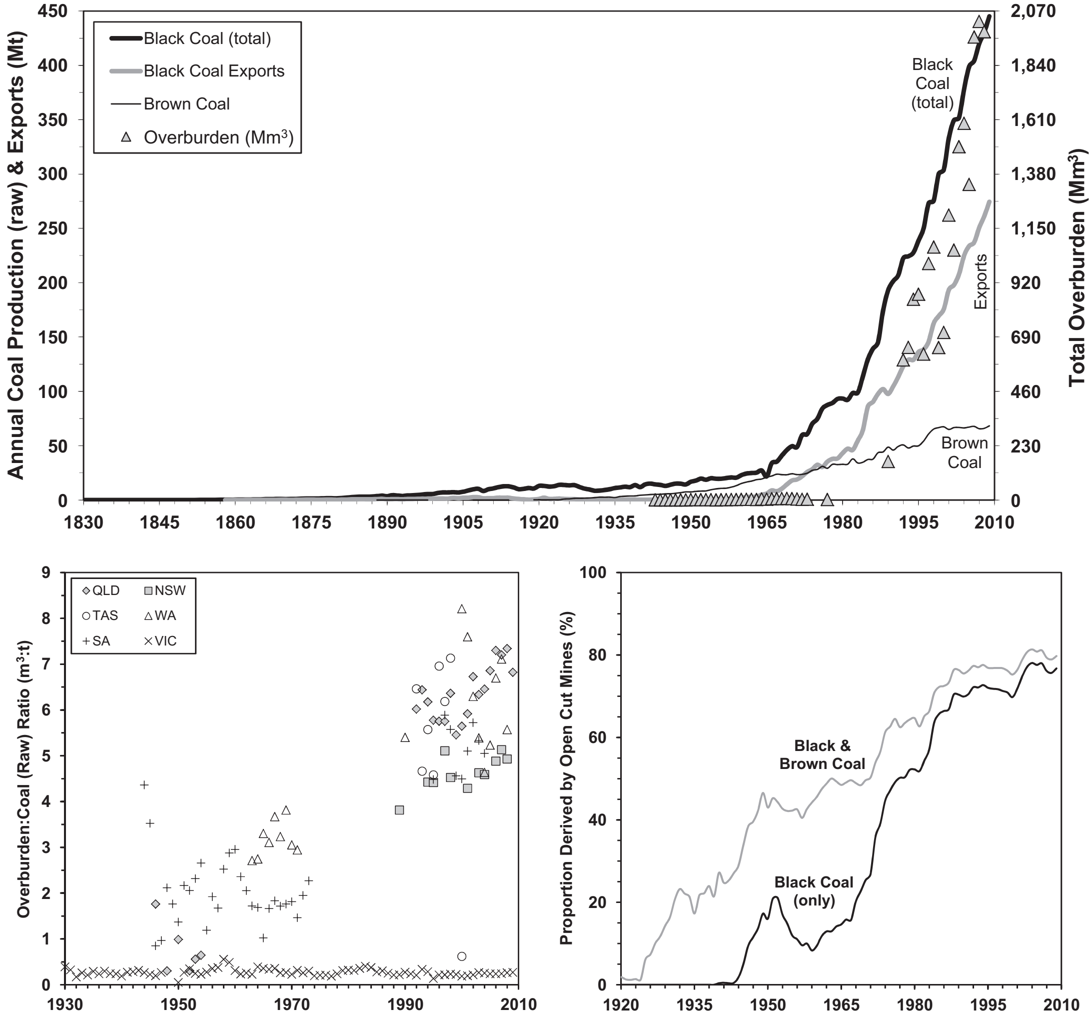

Fig. 2 – Australian historical coal production (top); overburden to raw coal ratios (bottom left); and fraction produced by open cut coal mines.

4.3. *Hunter Valley Coal Province, NSW*

For the Hunter Valley, although not all mines publicly report annual production data by individual mine, a total of 16 mines were able to be analysed in detail. Specific pollution intensities and developing trends over time of selected Hunter Valley coal mines are summarised in Table 4, including mine type (open cut, underground, or

Table 2 – Total metal, metalloid and air pollutant loads from coal mining over time for Australia.

	No. of mines	Metal & metalloid pollutants							Air pollutants			
		As (kg/year)	Se (kg/year)	Hg (kg/year)	Zn (t/year)	Cu (t/year)	Pb (t/year)	NO_x (kt/year)	PM_{10} (kt/year)	CO (kt/year)	SO_2 (t/year)	VOCs (t/year)
1998/99	19	86.2	N/A	0.7	N/A	<0.1	0.33	0.96	4.5	0.48	48	2.2
1999/00	42	1958	47	67	5.3	2.4	6.32	16.3	104	10.7	746	568
2000/01	68	2325	40	90	12.6	5.7	8.63	19.9	113	13.3	1037	718
2001/02	75	1858	164	57	34	9.3	5.88	24.8	130	15.4	1364	2437
2002/03	87	1553	190	53	37.1	10.2	5.27	34.5	129	18.9	1815	3879
2003/04	88	1778	230	64	45.9	10.7	5.8	36.3	134	18.5	1876	4105
2004/05	88	2001	234	66	47.6	14	6.28	48.6	171	25.2	1929	4110
2005/06	92	2322	171	178	52.2	15.1	7.75	42.3	184	24.4	1864	4535
2006/07	100	4460	246	161	75.3	17	8.28	62.2	197	28.9	2563	5470
2007/08	109	4003	1269	289	104.5	16.7	10.69	55.3	212	32.8	671	5745
2008/09	113	3042	1504	204	435.5	15.6	11.14	60.3	210	36.2	659	6366
2009/10	117	2818	783	95	339	16.2	9.39	63	216	39.4	656	7774

Table 3 – National and state average pollutant intensity associated with coal mining in Australia.

	Australia	NSW	QLD	TAS	SA	WA
Average coal production, Mt/year	293	121	162	0.387	3.43	6.33
As, mg/t coal	7.75 (I)	4.61 (I)	10.4 (D)	N/A	3.15 (D)	3.55 (I)
Se, mg/t coal	1.36 (I)	1.02 (D)	1.82 (I)	N/A	0.93 (I)	0.83 (I)
Hg, mg/t coal	0.36 (I)	0.37 (I)	0.04 (D)	0.82	0.08 (D)	0.16 (I)
Zn, g/t coal	0.33 (I)	0.55 (I)	0.20 (I)	N/A	0.03 (I)	0.23 (I)
Cu, mg/t coal	35.8 (I)	25.3 (I)	50.4 (I)	N/A	8.78 (I)	23.4 (I)
Pb, mg/t coal	23.7 (I)	14.1 (I)	31.0 (D)	1.19 (D)	6.07 (D)	37.9 (I)
NO_x, g/t coal	125 (I)	108 (I)	135 (I)	24.7 (D)	120 (D)	181 (I)
PM_{10}, kg/t coal	0.49 (I)	0.34 (I)	0.62 (I)	1.58 (D)	0.16 (D)	0.48 (I)
CO, kg/t coal	0.07 (I)	0.06 (I)	0.08 (I)	0.01 (D)	0.07 (D)	0.06 (I)
SO_2, g/t coal	4.30 (D)	4.07 (I)	4.39 (D)	0.80 (D)	3.62 (D)	6.56 (D)
VOC, g/t coal	12.1 (I)	9.44 (I)	16.0 (I)	2.51 (D)	11.7 (D)	13.0 (I)

both). The average pollutant intensities over time are shown in Fig. 5.

Almost all heavy metal pollutants showed an increasing trend from 1999/00 to 2007/08, except Se which shows a decreasing trend after 2002/03. Similarly, air pollutants other than SO_2 within the Hunter Valley region have substantially increased since 1999/00 (Table 4). PM_{10} is the most significant air emission with respect to both its intensity and steep increasing trend, showing a 62-fold increase from 8.8 g pollutant/t coal in 1999/00 to 544 g pollutant/t coal in 2009/10. This correlates with increased community concern over pollution issues in the Hunter Valley (see Higginbotham et al., 2010).

5. Discussion

At present in Australia, there remains strong political and economic support for the coal mining industry, mainly due to the export revenues it generates as well as coal use in electricity generation. However, the long term trajectory for coal is difficult to project given growing concerns over climate change and the need to reduce greenhouse gas emissions from fossil fuels use (see Mohr et al., 2011). Furthermore, community opinion is becoming more polarised, even in major coal provinces. In this paper, the focus has been on air and metal pollutants released from the mining stage only, and climate change issues are excluded. Given that Australia's coal industry will continue for some time at least, this places a greater emphasis on the need to understand pollutant loads and intensity associated with coal mining and linking this to community concern over local pollution impacts.

A major challenge with the NPI system is that it represents pollutant loads only and is not directly linked to standards or guidelines for pollutant concentrations in soil, air or water. This effectively implies an assumption that local monitoring would show if acute or chronic concentrations are reached due to high pollutant loads. In reality, there is virtually no direct linking of NPI data with regional or local environmental monitoring at present, though in intensive regions such as the Hunter Valley the need to do this is increasingly clear and urgent, especially given growing community concerns with pollution risks (Higginbotham et al., 2010). The respective environmental monitoring and NPI reporting is done in distant parallel and needs to be assessed in conjunction.

The reported emissions data are calculated from a facility's production characteristics and applying typical factors for certain activities. For example, sulfur dioxide emissions are calculated from diesel consumption based on the maximum sulfur level in diesel of 10 ppm, dust loads estimated from the hours of particular activities such as excavators or haul trucks, or metal concentrations contained in dusts (see Table 1 on pages 11–12, NPI, 2001). The problem, however, is that the emissions factors (and the formulae and actual data they are based on) are now over a decade old and the precise factors used at each mine are not included as part of NPI reporting. It is therefore not possible to independently estimate pollutant loads or investigate in detail the reasons for trends and magnitudes in reported NPI data. Furthermore, it is critical to link reported NPI data to actual operations, especially such management regimes such as dust suppression, haul truck and heavy vehicle maintenance, emissions control systems, mine design and planning, as all of these factors (and more) can influence the pollutants estimated to be released under the NPI approach. At present, the NPI cannot allow any of these potential factors to be linked to site operations, leaving somewhat uncertain the causes behind trends in NPI data for a given site.

In general, metal pollutant releases are much lower in mass terms than gaseous emissions, although it is not realistic to add metal and gaseous loads given the varying toxicity characteristics and risks of each pollutant. That is, a kilogram of mercury released to an aquatic ecosystem would present considerably more ecotoxicological risks than a kilogram of sulfur dioxide released to the atmosphere (i.e. acid rain risks). Furthermore, air emissions are more readily visible (i.e. particulates) and often attract the most public attention, but it remains important to keep monitoring metals given their commonly higher relative toxicity.

Gaseous pollutants and particulates (CO, SO_2, PM_{10}, $PM_{2.5}$, etc.) are almost entirely released to the air environment, whilst VOCs have a marginal proportion of emissions to land in NSW and QLD. However, emissions of metals are primarily split between air and water emissions. For example, in 2008/09 97% of Cu and 98% of Pb were released into the air, while 67% of Se and 83% of Zn from Australian coal mines are released into the water environment.

The case study of Hunter Valley suggests that, for most metal and gaseous pollutants, open cut coal mines have significantly higher pollutant intensities compared to

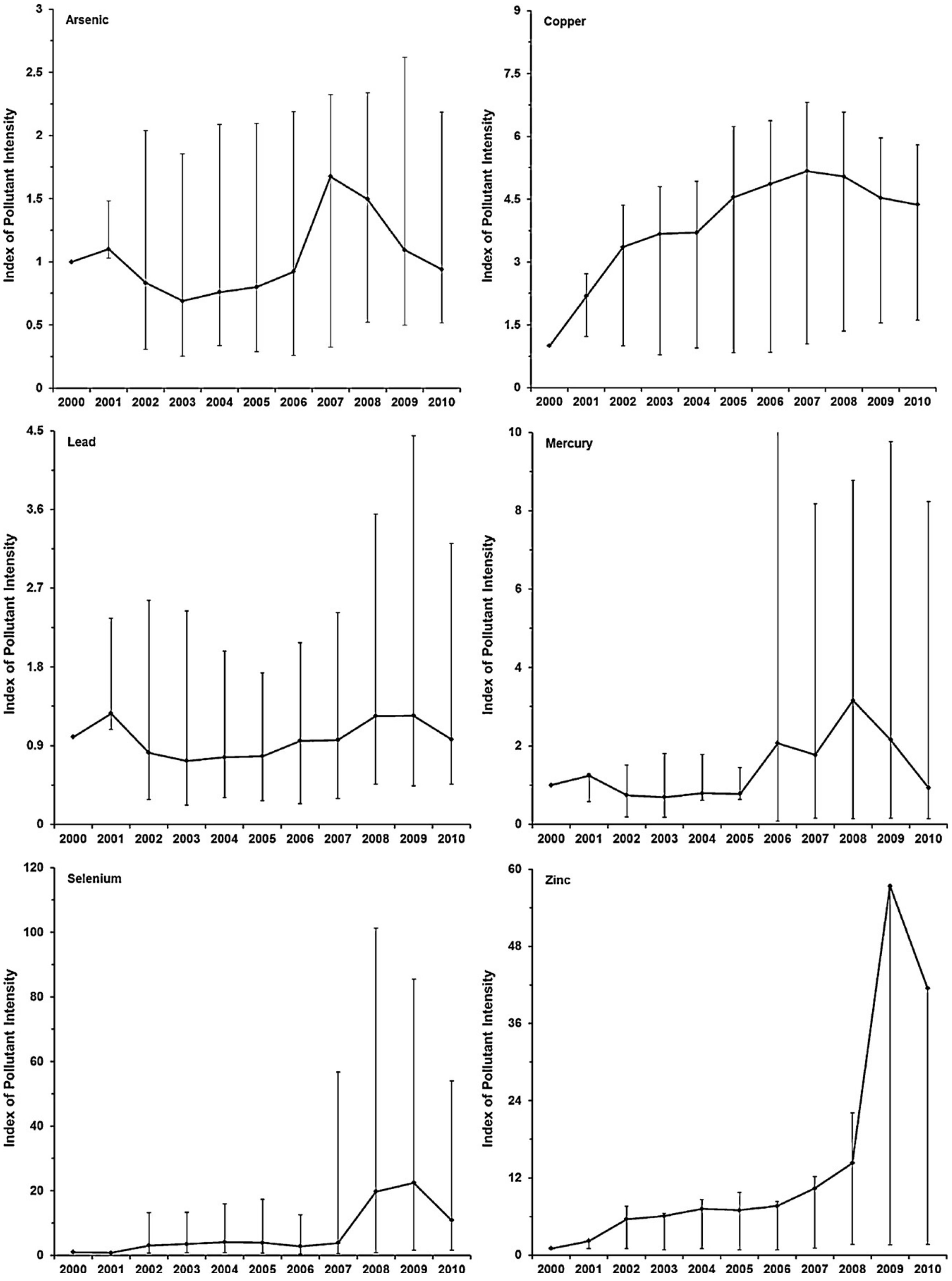

Fig. 3 – Pollutant intensity indices over time for metals from Australian coal production (indexed relative to 1999/00, including minimum/maximum state average indices).

Table 4 – Pollutant intensity of coal mines in Hunter Valley, NSW, including by mine type.

	Mine type	As (mg/t coal)	Se (mg/t coal)	Hg (mg/t coal)	Zn (g/t coal)	Cu (mg/t coal)	Pb (mg/t coal)	NO_x (kg/t coal)	PM_{10} (kg/t coal)	CO (kg/t coal)	SO_2 (g/t coal)	VOCs (g/t coal)
Ashton	OC & UG	10.41 (D)	7.29 (D)	0.17 (D)	0.74 (D)	209.6 (D)	76.6 (D)	0.38 (D)	2.21 (D)	0.18 (D)	17.0 (D)	31.9 (I)
Bengalla	OC	2.26 (D)	0.13 (D)	0.25 (I)	0.10 (I)	18.3 (I)	7.82 (I)	0.08 (D)	0.24 (I)	0.06 (D)	3.86 (D)	6.30 (D)
Bulga-Beltana	OC & UG	5.08 (I)	0.82 (D)	0.17 (I)	0.13 (I)	23.6 (I)	14.3 (I)	14.3 (I)	0.35 (I)	0.08 (I)	4.63 (D)	9.75 (I)
Camberwell	OC	11.8 (D)	1.45 (D)	0.09 (D)	0.74 (D)	70.1 (D)	32.3 (D)	0.35 (I)	1.06 (D)	0.16 (I)	13.3 (D)	24 (D)
Cumnock	OC	9.59 (I)	N/A	N/A	0.21 (I)	34.8 (I)	22.0 (I)	0.14 (I)	0.50 (I)	0.08 (I)	7.03 (I)	9.62 (I)
Drayton	OC	8.16 (I)	0.49 (I)	0.34 (I)	0.30 (D)	53.4 (D)	21.7 (I)	0.11 (I)	0.43 (I)	0.05 (I)	3.57 (D)	10.5 (I)
Glennies Creek	UG	0.83 (D)	0.18 (D)	N/A	0.02 (D)	3.48 (D)	2.92 (D)	0.06 (D)	0.05 (D)	0.02 (D)	N/A	N/A
Hunter Valley Operations	OC	5.88 (I)	0.69 (D)	0.29 (I)	0.20 (I)	37.3 (I)	17.9 (I)	0.14 (I)	0.64 (I)	0.08 (I)	6.74 (D)	9.24 (I)
Mt Arthur-Bayswater	OC	4.24 (I)	0.68 (D)	0.30 (I)	0.22 (I)	35.0 (I)	22.2 (I)	0.18 (I)	0.54 (I)	0.14 (I)	3.89 (D)	15.2 (I)
Mt Owen	OC	3.52 (D)	0.37 (C)	0.18 (D)	0.14 (D)	23.5 (D)	12.3 (D)	0.16 (D)	0.31 (D)	0.07 (D)	7.05 (D)	13.5 (D)
Mt Thorley-Warkworth	OC	4.33 (I)	0.35 (I)	0.26 (I)	0.18 (I)	29.0 (I)	12.7 (I)	0.10 (I)	0.48 (I)	0.08 (I)	6.05 (I)	6.50 (I)
Muswellbrook	OC	8.05 (I)	N/A	0.07 (I)	0.09 (I)	25.1 (I)	14.8 (I)	0.23 (I)	0.58 (I)	0.12 (I)	8.56 (D)	15.5 (I)
Narama	OC	6.20 (D)	7.36 (I)	0.32 (D)	0.21 (D)	35.7 (D)	16.4 (D)	0.09 (D)	0.37 (D)	0.07 (I)	4.92 (I)	5.82
Rix’s Creek	OC	10.1 (D)	0.88 (D)	0.36 (I)	0.27 (C)	50.5 (C)	26.5 (D)	0.37 (I)	0.78 (D)	0.23 (I)	17.3 (I)	27.8 (I)
United	UG	1.42 (D)	N/A	0.03 (D)	0.02 (D)	6.57 (D)	9.18 (D)	0.32 (D)	0.13 (D)	0.10 (D)	14.3 (D)	39.6 (D)
Wambo	OC & UG	2.64 (I)	0.31 (D)	0.14 (D)	0.09 (I)	19.1 (I)	18.5 (I)	0.13 (I)	0.44 (I)	0.07 (I)	4.34 (I)	8.74 (I)
Open Cut	11 mines	6.74	1.38	0.25	0.24	37.5	18.8	0.2	0.5	0.1	7.5	13.1
Underground	2 mines	1.13	0.18	0.03	0.02	5.03	6.05	0.19	0.09	0.06	14.3	39.6
Open Cut & Underground	3 mines	6.0	2.8	0.2	0.3	84.1	36.5	4.9	1.0	0.1	8.7	16.8

Notes: Additional production data sourced from NSWDPI (various); N/A: not available.

OC: open cut mine, UG: underground mine, OC & UG: projects with both open cut and underground mining.

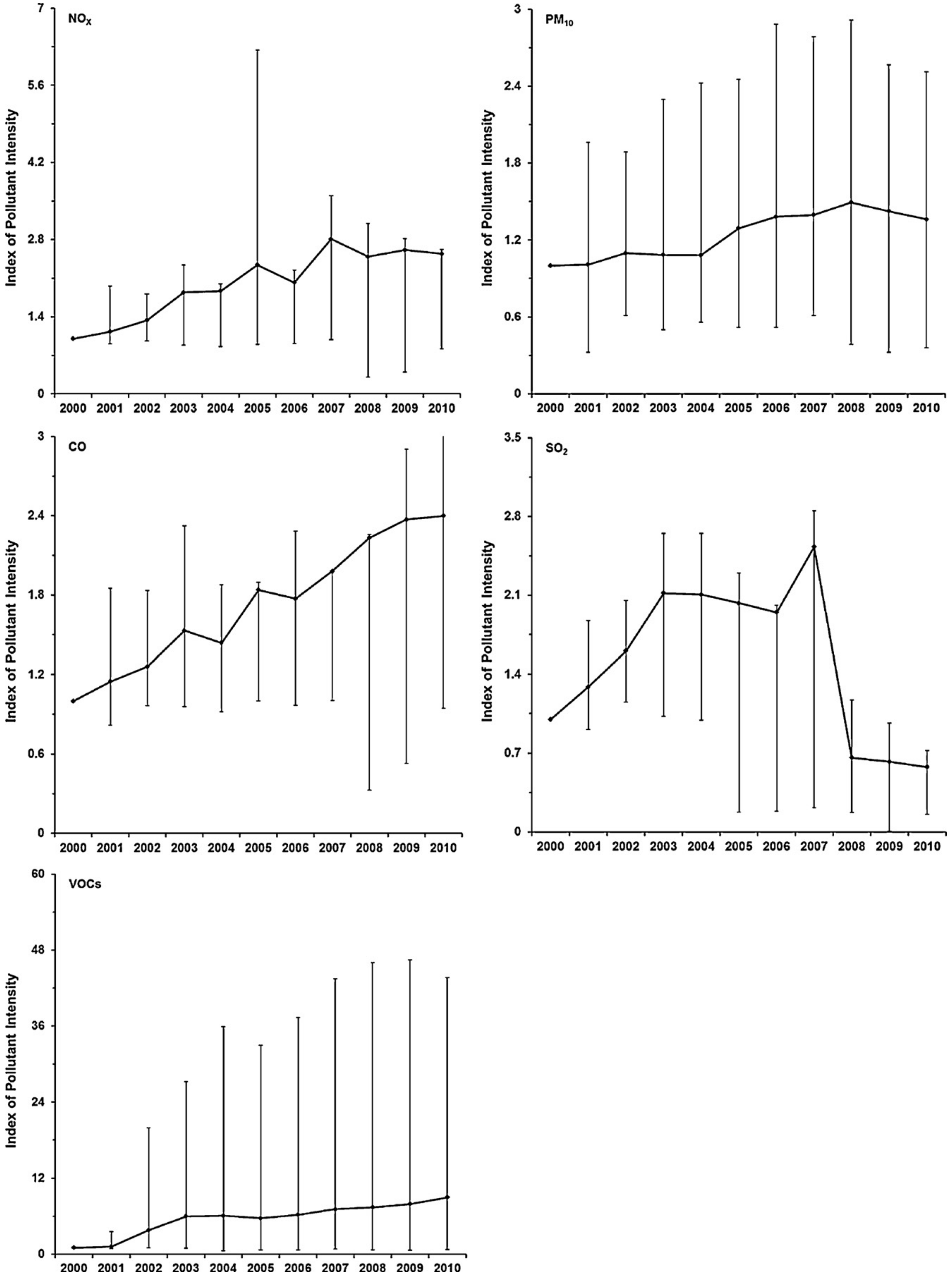

Fig. 4 – Pollutant intensity indices over time for air emissions from Australian coal production (indexed relative to 1999/00, including minimum/maximum state average indices).

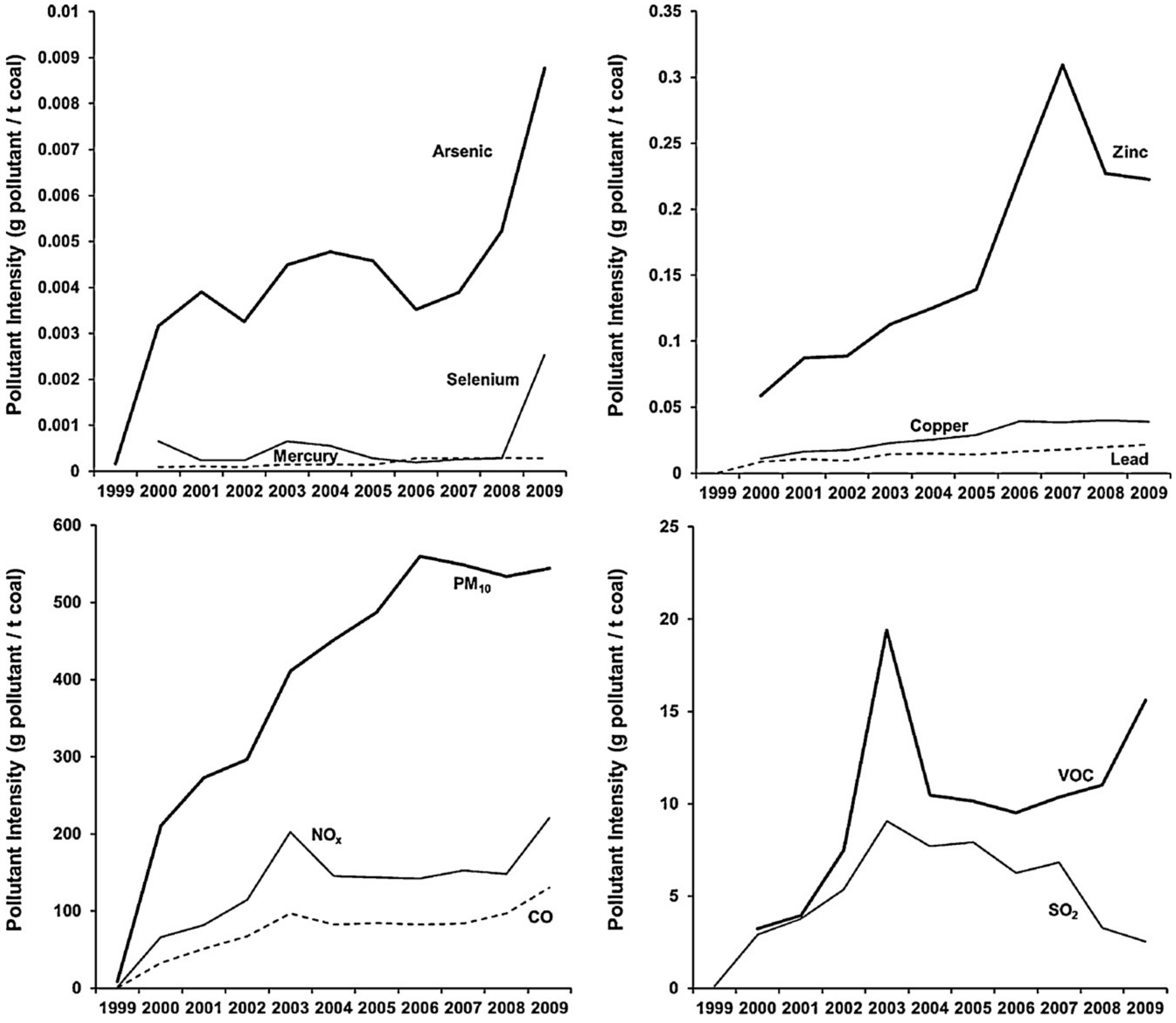

Fig. 5 – Average pollutant intensities over time in the Hunter Valley, New South Wales, Australia.

underground operations. The possible reasons for this include much higher material movements (excavators, haul trucks, rail), especially higher diesel consumption, large open cut voids for dust generation, as well as sizeable piles of overburden and waste rock. These aspects also increase the scale and complexity of water management, especially if there is any water discharged to the environment (either approved or accidental). Coal mines with both mine types have the highest level of Se, Cu, and Pb emissions while underground coal mines have more SO_2 and VOCs emissions. It should be cautioned, however, that the mixed and underground data are based on two and three sites, respectively. For SO_2 and VOCs from underground mines, the data are based on one site only (United) since the other underground mine did not report (Glennies Creek).

The analysis of the NPI data, especially with respect to normalised intensities over time, shows that despite significant efforts by coal mines over the past decade to improve their environmental management and performance, the key common trend is increasing pollutant burdens associated with every tonne of coal produced, with the only exception being SO_2. Given the statutory nature of NPI and the large number of mines included, approximately 80–100 mines for most years, the increasing pollutant intensities are therefore likely to be related to real increases in emissions and not merely an artefact of better reporting coverage. The reasons for the increase are difficult to ascertain, since the narratives provided in annual site reports are very minimal and do not allow a thorough understanding of site operations, nor are the reports and data sets used to estimate emissions publicly available to validate the NPI data. A possible factor could be the continually increasing scale of coal mines, leading to more mine waste, trucks, diesel combustion, exposed open cut faces and water management issues, although this requires further research. In addition, the trends could be indicative of declining coal quality, such as thinner seams requiring more overburden to be mined per tonne of coal (and associated dust issues), potentially higher impurities (e.g. metals, volatiles), or more volatiles released during coal washing. Given the contrasts between states (see Table 2 and Supplementary material), especially the lower rank coals from South Australia and Western Australia with higher rank coals from New South Wales and Queensland, this does not seem to be a key factor to date. The lack of linking NPI data to site operations also prevents a more detailed assessment of coal quality as a factor in pollutant release trends.

The wide variability in pollution intensities between states as well as between mines in the Hunter Valley suggests it may be possible to achieve much lower releases across the board than is currently recognised. For example, NO_x and SO_2 intensities vary from 24.7 and 0.80 g/t coal in Tasmania to 181 and 6.56 g/t coal in Western Australia, respectively (see Table 3). Similar differences can be observed in Table 4 for the Hunter Valley. As noted above, the lack of clarity on emissions factors and linking site operations to NPI data limits the ability to interpret the underlying causes behind these significant differences in pollution intensities.

Linking NPI data with state and national health statistics has been identified as a priority for informing policy makers on the short and long term impacts. These increased pollution burdens will impose on local mining communities and the surrounding environment. It is increasingly important to recognise the impacts that will occur to local populations and to link metal and air pollution trends with statistics such as fertility rates, cancer rates and ecosystem surveys to reveal, if any, cumulative impacts and identify and inform policies required to reduce these impacts.

Some other issues are less obvious with the associated data analysed in this study. Firstly, a major opportunity exists for NPI data (and PRTR data in general) to align with life cycle impact assessment (LCIA) databases, though at present there appears to be no substantive effort to link NPI and LCIA datasets in Australia. As NPI reporting continues over time, LCIA databases can be continually updated and refined to reflect contemporary scores in life cycle assessments. The toxicity aspects of emissions could also be addressed through LCIA methodology. Secondly, mine waste is excluded from NPI emissions reporting, since it is considered a land transfer only and not a specific emission to the environment. For an open cut coal mine, each tonne of raw coal excavated requires an average of 6 m^3 of overburden (Mudd, 2009), with some 1.6 billion m^3 mined in Queensland alone in 2009/10 (QDME, 2011). This overburden would contain a large mass of metals. Given that there are well known examples of former coal mines leaking acid mine drainage (AMD) to adjacent waters (see Mudd, 2010) – with AMD invariably carrying significant metal loads (Taylor & Pape, 2007) – this means that the NPI is potentially missing a large pollutant source term and long-term environmental risk.

6. Conclusion

This paper has compiled and analysed an extensive data set on Australian coal mining and associated pollutant emissions reported through the National Pollutant Inventory (NPI). In Australia, the coal industry has been growing rapidly over recent decades, and this is causing significant community concerns over cumulative environmental impacts. In general, the pollutant loads and intensities with coal mining are mostly increasing, pointing to the need to link NPI data with local and regional environmental monitoring, cumulative impact assessment and community and environmental health. Success is clearly possible, as shown by the significant reductions in sulfur dioxide emissions due to increasingly stringent diesel fuel standards. The NPI approach, however, is focused on the amount of pollutants released rather than strictly identifying the causes of pollution. Consequently, the influences of changes in emission factors and site operations could not be assessed or quantitatively analysed. This is a significant disadvantage of the current NPI system. With respect to mine types, the data for the Hunter Valley do show substantial differences between open cut, underground or mixed configurations, suggesting that open cut coal mines are, in general, more pollutant intensive compared to underground operations (with the possible exception of SO_2 and VOCs). In summary, the data, trends and issues identified in this paper provide an important basis to understand the value of pollutant release and transfer registers, such as the NPI, and demonstrate the critical need to integrate such data with ongoing trends in industry and environmental management initiatives to meet and successfully address pollution challenges.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.envsci.2012.03.003.

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