Air pollution in Australia: review of costs, sources and potential solutions

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Introduction

There is widespread recognition that air pollution causes ill health.[1] To promote sustainable policies, the World Health Organization (WHO) recommends quantifying environmental health effects and estimating their cost.[2] In Austria, France and Switzerland, particulate pollution was estimated to cause 40,000 premature deaths annually, about half attributable to motorised traffic.[2] More recently, a European Commission study attributed 310,00 premature deaths in 11 European countries to air pollution; average life expectancy of the entire population being reduced by nine months.[3] Using similar methodology, the Bureau of Transport and Regional Economics (BTRE) recently calculated the economic costs of air pollution from Australian transport.[4] However, all major pollution sources must be considered together to achieve the greatest reduction in pollution for least cost.

Of most concern are particles less than 2.5 μm (PM2.5). In Sydney, nephelometer measurements (which are highly correlated with PM2.5) were most significantly related to premature mortality and the only pollutant to remain significant fitting more than one pollutant in the same model.[5] Three independent US long-term cohort studies found significant relationships between PM2.5 and lung-cancer/cardiopulmonary mortality.[6-8] The largest involved 500,000 subjects and 120,000 deaths. A 10 $\mu g/m^3$ increase in annual PM2.5 increased cardiopulmonary mortality by 6-9% and lung cancer mortality by 8-14%.[8] Larger particles (2.5-10 μm and total suspended particles) were not consistently associated with mortality.[8] When

Abstract

Issue addressed: Estimated health costs and principal sources of air pollution are reviewed, together with estimated costs of reducing pollution from major sources in Australia.

Method: Emissions data from the Australian National Pollutant Inventory were compared with published estimates of pollution costs and converted to the cost per kilogram of emissions. Costs per kg of emissions (and, for the two main sources of pollution, diesel vehicles and wood heaters, costs per heater and per vehicle) are relatively easy to understand, making it easier to compare health costs with costs of pollution-control strategies.

Results: Estimated annual costs of morbidity/mortality exceed $1,100 per diesel vehicle and $2,000 per wood heater. Costs of avoiding emissions (about $2.1/kg PM2.5 for phasing out wood heaters and upwards of $70/kg for reducing diesel emissions) are considerably less than the estimated health costs ($166/kg) of those emissions.

Conclusions: In other countries, smokeless zones (for domestic heating), heavy vehicle low-emission zones, and lower registration charges for low-emission vehicles reduce pollution and improve health. Similar 'polluter-pays' taxes in Australia to encourage retrofitting of existing diesels and incentives to choose new ones with lowest emissions would provide substantial benefits. Adopting Christchurch's policy of phasing out wood heaters and 'polluter-pays' levies to discourage their use would be extremely cost-effective.

Key words: Air pollution, PM2.5, particulate pollution, cost, mortality, morbidity.

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So what?

According to the World Health Organization, there is no safe level of fine particle air pollution. Policy makers and the public need to understand the costs and sources of air pollution to be able to achieve maximum reduction in emissions for available expenditure. Reduced taxes for low polluters and increased taxes for high polluters, e.g. by 'polluter-pays' levies proportional to estimated health costs, would be an efficient and equitable way to safeguard community health.

the first study, involving six cities, was followed up, PM2.5 had dropped substantially in one city, moderately in another, remaining stable elsewhere. Death rates fell in the first two cities relative to the other four.[9] Animal experiments and epidemiological studies show PM2.5 cause pulmonary inflammation, increasing the risk of ischemic heart disease, dysrhythmias, heart failure, and cardiac arrest.[10,11]

Using the latest dose-response relationships, the Australian National Environment Protection Council (NEPC) estimated that, in Sydney, Melbourne, Brisbane and Perth, PM2.5 pollution causes a total of 1,611 premature deaths annually (1,661 including bushfire events), with roughly double that for the entire country.[12] Thus estimated costs of PM2.5 pollution are now higher than estimates for all pollutants in the 1998 Air NEPM (PM10, particles <10 μm, 2,400 deaths costing $17.2 billion; CO, $6 million; NO_2, $5 million; O_3, $810 million; SO_2, $1.4 million; Pb, $25-680 million).[13,14]

The NEPC set advisory standards for PM2.5[12] – maximum 24-hour average 25 μg/m^3; maximum annual average 8 μg/m^3. If made mandatory when reviewed in 2005, these standards would be hard to achieve. In 2001, a majority of monitoring sites exceeded 8 μg/m^3. In Sydney, the sixth highest daily average PM2.5 was 40 μg/m^3. Even when standards are achieved, the NEPC acknowledges PM2.5 will cause 1,000 premature deaths/year.[12] In 2000, believing there is no safe level of PM pollution (where no adverse health effects are observed) the WHO chose not to set guidelines for PM.[15]

In Australia, the NEPC sets national air quality standards, but States and Territories are responsible for achieving them. The main Federal Government contribution was to set fuel standards and emissions limits for new vehicles. However, other Federal Government initiatives, e.g. replacing fuel excise for vehicles over 4.5 tonnes with a road user charge, may increase pollution by encouraging greater use of existing diesels. Phasing in excise duty from 2011-15 on low-polluting fuels such as LPG and natural gas may also cause increased pollution. This paper reviews emissions data, identifies major PM2.5 sources and relates estimated costs to the amount of emissions (kg). Possible control measures to reduce health impacts and meet the air quality standards are compared and discussed.

Methods and data

At present, the Australian National Pollutant Inventory (NPI) lists only PM10 emissions. However, coarser particles (>2.5 μm) usually originate from mechanical processes, e.g. wind erosion,[12] whereas combustion-derived emissions are much smaller.[12] The size distribution of vehicle exhaust PM peaks between 0.1 and 0.2 μm;[16] wood heater PM peaks 0.05-0.2 μm[17] with virtually no PM greater than 1 μm.[18] Table 1 lists all sources emitting at least 10% of PM in any capital city airshed, excluding dust from unpaved/paved roads and coal mining emissions (where coarser particles are expected to predominate).

Transport emissions

Table 2 shows BTRE estimates of PM10 exposure and costs of transport pollution for Australian capital cities. The methodology,[2] published in the *Lancet*, is widely known and used elsewhere, e.g. New Zealand (NZ)[19] and the European Commission study.[3] Exposure above background level (which BTRE assumed was 5 μg/m^3)[4] was calculated from population-weighted averages of measurements at all monitoring stations. Health effects were calculated from published estimates of relative risks (RR) for a 10 μg/m^3 increase in PM10 exposure:[2] mortality, adults ≥30 years (RR=1.043), respiratory/cardiovascular hospital admissions (RR=1.013), chronic bronchitis incidents, adults ≥25 (RR=1.098), bronchitis episodes, children<15 (RR=1.306), restricted activity days, adults ≥20, (RR=1.094) and asthma attacks (children<15, RR=1.044; adults ≥15, RR=1.039). RR for mortality[2] were based on long-term studies identifying PM2.5 as the most significant pollutant (irrespective of source), but converted to PM10 equivalences because of the wider availability of PM10 measurements.

Numbers of deaths increase with increasing pollution. One estimate is that, on average, 10 years of life are lost.[4] However, no particular death can be attributed directly to air pollution, so researchers describe the association as 'statistical'. BTRE

Table 1: Annual PM10[a] emissions (tonnes) to airsheds surrounding Australian capital cities from all sources representing at least 10% of total emissions in any one airshed (Source: NPI, 2001/02).

Airshed	Syd metro[b]	Port Philip	SE Qld	Adelaide	Perth	Hobart	ACT	Darwin	Total
Vehicles	5,800	3,500	2,200	570	1,600	180	92	69	14,011
Domestic solid fuel	3,100	6,900	89	1,500	2,300	2,100	640	0	16,629
Electric supply	3,100	430	–	330	340		0.1	180	4,380
Iron/steel manufacturing	2,500	150	83	13	–	–	–	–	2,746
Bushfires/burn-offs	1,500	590	15,000	–	1,900	190	46	5,800	25,026

(a) The NPI (www.npi.gov.au) lacks PM2.5 data, so Table 1 is based on PM10 (particles <10 μm), excluding dust from paved and unpaved roads and coal mining emissions (assumed to consist mainly of coarser particles >2.5 μm).

(b) The Sydney Metropolitan Airshed covers Sydney, Wollongong and Newcastle.

estimated the value of a statistical life (VOSL) at $1.3 million, using the human capital method to value life years lost.[4] European estimates are either marginally (0.9 million euro, $A1.5 million) or substantially higher (2-3 million euro). The 1998 Australian NEPM used an even higher value ($A7 million). BTRE noted that its estimate was conservative; the willingness-to-pay method, based on what people would pay to reduce risks to their lives, generally yields much higher values.[4] For morbidity, BTRE estimated the number of 'healthy' years lost to disability (YLD) using hospital admissions data and the published RR, valuing each YLD at $50,000.

Estimated costs of vehicle emissions in each capital city were divided by total kg of vehicle PM emissions to the entire surrounding airshed, to derive conservative estimates of the cost per kg of emissions (see Table 2).

Results

Cost per vehicle

The substantial health costs of air pollution from transport in Australia ($2.7 billion, see footnote, Table 2) may be appreciated by expressing them per vehicle – $202/vehicle/year for 13.2 million vehicles. However, simple averages may be misleading; vehicles emitting pollution in densely populated areas incur greater costs; pollution standards permit heavy vehicles to have higher emissions (g/km). Diesel vehicles (numbering 1.2 million) emit 50-80% PM,[4,20] so estimated health costs are $1.3-$2.1 billion – $1,110-$1,775 per diesel vehicle/year. Policies do not discourage diesels, which increased from 7.4% of vehicles in 1999 to 9.3% in 2003.

Petrol cars with catalytic converters (required for all new Australian vehicles since 1986) emit about 0.01 g/km[21] plus 0.006 g/km PM2.5 from brake wear.[22] In simulated urban driving (cold start, many stops) well-used US cars (1977-1983 catalyst models; odometer readings 27,000-149,000 miles) had similar exhaust emissions (0.01 g PM2.5/km).[23] Using the estimated costs per kg of emissions (see Table 2), annual costs per petrol-fuelled catalyst car (15,000 km/yr) range from $43 (Sydney) to $15 (Hobart).

Australian diesel passenger cars/off-road vehicles have much higher emissions: 0.75 g/km (1980-89 models), 0.41 (1990-95) and 0.26 g/km (1996-99 models).[21] Thus a 1980-89 diesel passenger car/utility emits about 11 kg PM2.5 (15,000 km/yr) with estimated cost of $1,965 (Sydney) and $672 (Hobart). PM emissions from older diesel vehicles were unrelated to vehicle mass; pre-1990 diesel cars had similar emissions to much heavier trucks.[21] New models should be 97% cleaner by 2007. Euro-2 (0.08 g/km for diesel vehicles <1,250 kg) was mandated from 2002/3; Euro-4 (0.025 g/km) from 2006/07.

Table 2: Annual health costs of transport emissions in capital cities (BTRE estimates, A$ millions, based on data for 2000),[4] estimated cost per kg of PM10 emissions and estimated health costs of woodheater emissions.

Airshed City	Syd metro[a] Sydney	Port Philip Melbourne	SE Qld Brisbane	Adelaide Adelaide	Perth Perth	Hobart Hobart	ACT ACT	Darwin Darwin	Total
Average annual PM10 exposure and percentage of exposure due to vehicle emissions									
PM10 ($\mu g/m^3$)[a]	18.0	18.0	18.7	19.0	18.8	16.0	16.3	14.9	
Vehicle %[a]	43	33	31	19	20	10	12	37	
Annual health costs of transport emissions									
Deaths (n)[a]	549	344	151	87	80	6	6	4	1,228
Cost ($m)[a]	713	448	197	113	104	8	8	5	1,596
Morbidity (n)[a]	1,071	682	321	168	165	10		9	2,425
Asthma attacks[a]	392	593	181	52	50	0		0	1,269
Morb. cost ($m)[a]	323	211	98	49	49	3		2	735
Total cost ($m)[a]	1,036	658	295	162	153	11	8	7	2,330
Cost ($/kg)[b]	179	188	134	284	96	61	87	101	166[c]
Annual health costs of woodheater emissions[d]									
Cost ($ml)	554	1,297	11	426	220	128	56		2,692
No heaters[e]	351,800	240,900	128,700	107,400	176,400	104,700	6,700	1,800	1,118,400
Cost ($/heater)[f]	1,574	5,385	82	3,969	1,247	1,226	8,306		2,407[c]

(a) BTRE estimates;[4] morbidity cases (number of admissions) and asthma attacks tabulated separately, except ACT where no morbidity data available.[4] The Australia-wide total cost of transport emissions was $2663 million.

(b) Obtained by dividing the cost of transport emissions in each capital city by kg of transport emissions to the surrounding airshed. This is an under-estimate, particularly for Sydney, where health costs of transport in Sydney were divided by transport emissions for the entire metropolitan airshed (Sydney, Newcastle and Wollogong). The true cost, see discussion, is likely to be substantially higher; less conservative estimates per kg PM2.5 would emphasise the importance of control strategies.

(c) Costs (per kg of emissions and per woodheater) averaged over all capital cities.

(d) Calculated by multiplying kg woodheater emissions in the airshed by estimated cost/kg (derived from transport emissions).

(e) Number of households in the entire State using wood as the main form of heating (from ABS report 4602.0).

(f) Estimated cost of emissions (in the airshed) divided by the number of households in the entire State using wood as the main form of heating.

Other PM emissions

Table 1 shows other major PM2.5 sources in capital city airsheds. Health costs depend on population exposure, which depends on quantity, location and timing of emissions. Wildfires and burn-offs emit more total PM2.5 than any other source (see Table 1). However, emissions are spread over a wide rural area; only 50 of 1,661 estimated premature deaths in Brisbane, Sydney, Melbourne and Perth were attributed to bushfires.[12] None the less, in Brisbane, mortality was significantly related to nephelometer (PM2.5) measurements both in summer and winter.[24] Given the magnitude of emissions, especially in south-east Queensland, additional strategies to reduce this pollution should be considered.

The Sydney Metropolitan Airshed has some industrial emissions (13 iron and steel and 12 electricity-supply facilities). Few are close to major Sydney population areas, so exposure is probably much less than transport or wood heaters, and declining. Pollution-reduction plans include $95 million for Port Kembla.[12] Electricity-supply emissions fell from 3,100 tonnes in 2001/02 to 2,500 tonnes (2002/03). Modern power stations with fabric filters and 200 m stacks are claimed to have negligible PM concentration at ground level.[13]

A major source of Sydney's winter pollution was identified as wood heaters (used by about 13% of households).[25] PM10 were collected in July/August 1993, when there were no bushfires, from 4 pm to 8 am next day. At Rozelle, near the CBD, 67% of all carbon was modern, i.e. from wood, not coal, diesel or petrol. In the Blue Mountains, the proportion was 81%[25] and 90-100% in Duncraig, a Perth suburb.[26] Air toxics, e.g. polycyclic-aromatic-hydrocarbons (PAH), are another concern. Winter PAH averaged 4.47 ng/m^3 in Sydney, seven times the summer average of 0.62 ng/m.[3,27] NPI data show wood heaters emit 48% of PAH in the Sydney metropolitan airshed (44% and 67% in Melbourne and Canberra).

Wood heater PM emissions totalled 19% more than transport (see Table 1). Overall population exposure to wood smoke PM is therefore expected to be similar to transport PM. First, because wood heaters emit more tonnes of PM2.5; second, because diesel vehicles (in NSW emitting 80% of PM for only 15% of vehicle km[20]) transport goods between, as well as within, residential/commercial areas of cities, but wood smoke is emitted where people live, often during temperature inversions, which trap pollution, allowing it to build up. PM2.5 are minuscule so, like the oxygen we breathe, they readily penetrate indoors. PM2.5 inside homes is generally similar to outdoor levels;[28] new, well-sealed wood-heated houses may have much higher PM2.5 than outside.[28]

Both PM pollution and deaths are generally higher in Sydney in winter when a substantial proportion of PM2.5 is from wood smoke.[29] This may be partly due to seasonal effects, but it is interesting that on the 25% of days with lowest nephelometer readings, Sydney averaged 54 deaths/day, compared with 60 on the highest 25% of days.[29]

Cost per woodheater

A crude under-estimate of the cost per wood heater is the cost of emissions in capital cities, divided by the number of households (in the entire State) using wood as main heating. The results – thousands of dollars per heater per year (see Table 2) – highlight the importance of reducing wood smoke. Other research supports these values. In Armidale (NSW Northern Tablelands, population 21,000), conservative estimates (mortality only, estimated from average PM2.5 population exposure and VOSL of $1.6 million) were $6.4 million/year – $1,800/woodheater/year.[30] This was based on the lowest plausible RR of 0.2% increased mortality per additional 1μg/m^3 of annual PM2.5. Using the NEPC's RR[12] of 0.6%, costs would be three times higher – $5,400/wood heater/year.

Estimated costs are substantial because emissions are substantial. In a recent audit, seven out of 12 new wood heaters failed the Australian standard (AS4013).[31] New, perfectly operated heaters averaged 6.3 g/kg fuel in laboratory tests; one emitted 17.8 g/kg.[31] Real-life emissions can be much higher; lab tests exclude the initial lighting period (with emissions up to 40 g/kg); the lowest air setting (with highest emissions per kg fuel) usually provides enough heat for the average living area.[32]

Unlike other appliances, careless operation can produce up to 100 times more smoke than using a wood heater really well.[33] Some householders burn green wood (or treated timber, producing highly toxic emissions), or bank up the fire for overnight/unattended burning by overfilling the firebox then immediately reducing air intake to minimum. The fire smoulders for up to 12 hours, producing tremendous quantities of smoke, but little heat.

Because of the above, laboratory emissions of 6.3 g/kg most likely equate to real-life emissions exceeding 10-20 g/kg. Households with wood as main heating burn an average of 4.8, 4.3 and 2.0 tonnes/yr (in Tasmania, Victoria and NSW[34]). Burning two tonnes in a heater emitting 10-20 g/kg produces 20-40 kg PM2.5. Emitting 30 kg PM2.5/year costs an estimated $5,359/year (Sydney) and $1,833/year (Hobart, see Table 2).

Discussion and policy options

Obtaining universally agreed estimates of health costs is not easy. A monetary value is required for human life and suffering. Total mass of emissions must be related to measured pollution concentrations, which are weighted by population density to calculate exposure. The BTRE and NEPC dealt with uncertainties by being conservative – stating their values underestimate the true cost, representing what is 'at least' attributable to pollution.

Similarly, costs presented here per diesel vehicle, wood heater and kg PM2.5 emitted also underestimate the true cost.

Comparison with other published estimates

Other published estimates are similar, or higher. In Sweden, estimates ranged from A$1,250/kg PM2.5 (inner Stockholm), A$942 (Gothenburg), A$788 (Malmo), and A$558 (Uppsala) to A$308 (outer parts of Greater Stockholm).[35] In Europe, the EC developed the ExternE methodology to quantify emissions, assess resultant pollution concentrations (e.g. using dispersion models), estimate population exposure, calculate adverse health effects from RR and estimate economic costs. In urban areas, costs ranged from 900 euro/kg (central Athens), 700 euro/kg (London), 400 euro/kg (Brussels), 200 euro/kg (Stuttgart).[21]

Although costs vary with location, per-kg estimates provide a simple, easy-to-use way of comparing pollution costs with costs of control measures. This is particularly true for vehicle PM2.5, which may be emitted anywhere. The Australian Diesel NEPM compared policy options using an estimate of $225/kg (including $129/kg for mortality and $95/kg for morbidity), derived from European data for a city of one million.[35]

Research, commissioned by the Commonwealth Government, modelled the relationship between population density and costs per kg from ExternE to derive estimates for Australia. These were $342/kg PM2.5 (inner Sydney, Melbourne, Brisbane, Perth, Adelaide), and $93/kg (other urban areas including Canberra, Hobart, Darwin and outer areas of larger capital cities).[21] Thus Table 2 is broadly consistent with other published estimates.

Research continues into costs of PM pollution. Baby mice, born to mothers living in clean air, had twice as many genetic mutations if their fathers spent 10 weeks in an area of high PM pollution as those of fathers from clean air. PM was considered the main cause; mutations were 52% less if fathers were protected from PM (but not gaseous pollutants) by a particle filter.[36] Genetic damage, linked to PAH from air pollution (at much lower levels than where wood smoke builds up in Australia) was also found in human babies.[37] The monetary cost of these health effects has not been estimated.

Low emission zones

Having created smokeless zones to tackle solid-fuel emissions, Greater London plans to reduce diesel pollution by a Low Emission Zone (LEZ) from 2006/07,[38] following progressively tighter emission limits for new vehicles – Euro-1 (1993), Euro-2 (1996/7), Euro-3 (2001), Euro-4 (2006). To enter the LEZ, lorries, coaches and buses not satisfying Euro-3 will need a particle trap.[38] Only taxis meeting Euro standards will be licensed; scrapping pre-Euro vans will be encouraged. The plan is to progressively tighten requirements, so all heavy vehicles satisfy Euro-4 PM standards by 2010. Despite the cost, nearly 80% of freight operators agreed with the proposals.[38] LEZ for freight vehicles already improve air quality in Stockholm, Gothenburg, Malmo and Lund, and are being widely considered by other UK and European cities.[38]

Australian standards for new diesel vehicles lagged behind the US and Europe. A 1997 report noted that, although Australian light commercial vehicles (LCV) are a significant source of urban diesel emissions, US LCVs are mostly petrol, reflecting tighter US emissions standards for diesels.[39] The first Australian PM standard for diesels under 3.5 tonnes was Euro-2, introduced in 2002/03 along with low-sulphur (500ppm) diesel. Euro-4 (and ultra-low-sulphur (50ppm) diesel) is scheduled for 2006/07.

The Australian Diesel NEPM discussed ways to reduce emissions; State and Territory jurisdictions choose what measures to implement. So far, emphasis has been on in-service testing. To December 2003, NSW and Victoria tested 2,000 vehicles; 200 were repaired, with average emissions-reduction of 30%. Pollution from older diesels is substantial; in-service standards for pre-Euro-2 vehicles under 3.5 tonnes are 0.23 g/km/tonne – i.e. 0.69 g/km for a three-tonne 4WD/LCV, little different to the in-service standard (0.78 g/km) for a 1996 26-tonne truck.[35] Thus a pre-Euro-2 diesel LCV/4WD travelling 20,000km in Sydney emits 13.8kg PM2.5 with estimated cost $2,465.

In the UK, the Government funds 75% of the cost of fitting diesel particulate traps or oxidation catalysts; low-emission vehicles have lower annual registration fees.[40] Australian schemes could be revenue neutral (reduce costs for low-emission vehicles and increase charges for high polluters) yet provide substantial health benefits. Public awareness of the magnitude and cost per vehicle of emissions, especially older, diesel cars/LCV (with low current market value), may stimulate discussion and perhaps implementation of additional pollution-reduction strategies, e.g. LEZ, 'polluter-pays' taxes, retrofitting, or converting to cleaner fuels. In 1997, the cost of using LPG-fuelled buses instead of diesel was about $70 for each kg of avoided PM2.5 emissions.[39]

Solid fuel heating

When PM2.5 pollution was reduced in Dublin by banning non-smokeless coal in September 1990, there were 15.5% fewer respiratory and 10.3% fewer cardiovascular deaths in the six years after the ban, compared with the previous six years (116 fewer respiratory and 243 fewer cardiovascular deaths/year).[41] This reduction, sustained over six years, represents a substantial benefit far greater than the cost of switching to less polluting heating.

Wood smoke is a known health hazard. A US-EPA study, using the Ames bacterial mutagenicity test and tumour-initiation tests on mice, found it was 12 times as mutagenic as the same quantity of cigarette smoke.[42] Woodstove use was linked to 30% of mouth and throat cancers in Brazil.[43] Smoke from biomass cooking fires is the fourth largest cause of death and disease in developing countries, killing more children under five than malaria, measles or AIDS.[44] Australian bushfire smoke was found to be as injurious as to health as particles from other sources.[45]

Wood heaters became popular in Australia in the 1980/90s, increasing from <3% of Sydney households in 1979 to 13% in 1995.[25] Fuel from land clearing and dieback was abundant and cheap. Purchasers liked the ambience but were unaware of the magnitude and cost of emissions, or that careless operation vastly increases pollution. One expert noted: "Community education programs on correct wood heater use have been tried in Launceston since about 1992 and seem to have made little difference. Perhaps the education programs were poorly designed and better approaches are possible, but several different groups have tried, with different approaches and no clear success has been observed."[46] Launceston now aims to reduce number of wood heaters by two-thirds within five years, e.g. by banning wood heaters in new houses or extensions.[47]

Wood smoke reduction programs have limited funding. Private industry spent $95 million reducing emissions from one plant (Port Kembla), but only $0.65 million was available in 2002 for wood smoke reduction throughout NSW. Despite estimated health costs of thousands of dollars per heater per year and higher winter air pollution measurements than Sydney, Armidale ceased wood smoke education, wood heater buybacks and measuring air pollution in 2003 when State funding ceased. Given the substantial costs and limited success of current wood smoke reduction programs, 'polluter-pays' policies should apply to both domestic and commercial emissions. Annual woodheater licences could fund education, smoke patrols, buyback schemes and the health costs of pollution. Licences could be withdrawn if owners fail to operate heaters correctly.

In Christchurch (population 333,000), New Zealand, wood heating causes 90% of PM pollution.[48] Epidemiological time-series studies revealed significant relationships between PM pollution and both mortality[49] and hospital admissions for cardio-respiratory illness.[48] PM pollution causes an estimated 182 deaths per year.[1] Christchurch is phasing out wood heaters, except ultra-low emission models (<1g/kg fuel) that replace more polluting heaters. Elsewhere in New Zealand, if heaters are allowed, the emissions limit for installations on properties <2ha was reduced from 4 to 1.5g/kg.[50]

A ban on wood heaters (phased in over 10 years) was suggested by the 1997 Australian NEPM discussion paper, with estimated cost of $2.1/kg PM emissions avoided.[39] In most cities, buying firewood costs more than using heat pumps or flued natural gas heaters.[51] With home insulation, thermostatically controlled systems are substantially cheaper, because no heat is wasted. Owners commonly use wood heaters overnight and in warm periods of the day, to avoid the bother of relighting. This increases cost, energy consumption, pollution and greenhouse gas emissions.

Because it is assumed the trees are being replanted, wood heaters are popularly considered greenhouse-neutral. However, a substantial proportion of current firewood production (from land clearing/native forests) is non-sustainable, depriving wildlife, including threatened species, of hollow logs for homes. Each tonne of non-sustainably sourced firewood emits 2.0 tonnes CO_2-equivalent,[17] compared with 0.7 tonnes to heat the average Sydney home with natural gas.[51] Careless operation substantially increases greenhouse emissions, producing up to 30kg methane (0.69 tonnes CO_2-equivalent) per tonne of wood.

Ideally, wood heaters would be replaced with solar heaters. The simplest/cheapest designs have a transparent cover over a black metal absorber and a fan to transport heated air to living areas.[52] Solar heaters (much cheaper than photo-voltaic systems) could be integrated into roofs of new buildings, or retrofitted to existing roofs, for less than the cost of a wood heater. Even with backup-heating, annual running costs and greenhouse emissions should be far less than wood heating. Sustainably harvested wood no longer needed for wood heaters could replace coal in power stations or produce ethanol as partial replacement for petrol, reducing overall greenhouse emissions.

Conclusions

Studies cited here show PM pollution causes heart and respiratory disease, lung cancer,[8] and premature deaths of more than 3,000 Australians[12] and 970 New Zealanders[1] annually. Controlling pollution to meet the PM2.5 standard is therefore of interest to both health professionals, policy makers and the general public. Policies in other countries recognise PM2.5 has the most significant impact on health. In California, diesel exhaust is listed as a toxic air contaminant.[53] In Europe, smokeless zones for domestic heating, LEZ for diesel vehicles and pollution-related registration charges provide substantial benefits. More than 2,000 lives were saved, for very little cost, in the first six years of Dublin's ban on smoky coal.

Australia has no LEZ, nor smokeless zones; polluting wood heaters continue to be installed. Reducing car dependence has many benefits,[54] and petrol cars contribute to BTEX emissions,[55] secondary ozone and about 40% of NOx from transport in London. However, estimated health costs of these pollutants are considerably less than those due to PM, of which the two major sources are wood heaters and diesel vehicles.

Estimated costs per kg PM2.5 emissions provide a simple way of comparing the efficacy of different pollution-control measures. In conjunction with data on average use, they provide an easily understood way of informing the public and policy makers of the cost of pollution from commonly used equipment.

The lowest plausible estimates of the cost per kg emissions in urban areas indicate there are practical, cost-effective strategies, e.g. using 'polluter-pays' principles, to tackle major sources of PM2.5 pollution, especially wood heaters and diesel engines, and encouraging users to switch to cleaner heaters/ vehicles, use cleaner fuels (e.g. LPG, CNG) or install catalysts/ particle traps.

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