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WIND ENERGY, CLIMATE AND HEALTH: EVIDENCE FOR THE IMPACTS OF WIND GENERATED ENERGY IN AUSTRALIA

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The Australia Institute
Research that matters.

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Technical Brief

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Summary

Wind power is one of the least greenhouse gas intensive energy sources available and Australia has some of the best wind resources in the world. With the potential to produce up to 40 per cent of Australia's electricity needs, wind power presents a great opportunity for reducing our national greenhouse gas emissions and heavy reliance on fossil fuels.

Public polling by The Australia Institute[1] reveals strong public support for wind power, with 84 per cent of people ranking it within their top three preferred sources for meeting Australia’s future energy needs. This stands in strong contrast to coal and coal seam gas (CSG), which were listed among the top three energy sources by a mere 38 and 35 per cent of Australians respectively.

Despite broad public support and the capacity for wind power to contribute more significantly to Australia’s energy supply, public discussion is often clouded by vocal opponents of this renewable energy source. Arguments made against wind energy are usually grounded in health or environmental concerns. This paper explores the nature and validity of these arguments to determine the overall impact of wind power technologies in the Australian context.

Among the outspoken critics of wind farming are some members of parliament, such as the Treasurer Mr Joe Hockey, who described wind turbines as “utterly offensive” and “a blight on the landscape”.

The paper finds, however, that a strong majority disagree with this opinion, with 80 per cent of people polled saying they do not consider wind turbines to have a negative impact on the landscape. In contrast, public perceptions of fossil fuel-based energy sources are less positive, with 68 per cent and 41 per cent of people respectively considering coal and CSG to have a negative impact on the landscape.

Though wind turbines have been linked to bird and bat deaths, rates are relatively low, especially when considered in the context of the impact of climate change. The paper also finds that technological advances are likely to reduce these ecological impacts even further. Other environmental impacts from wind farms are low and they can co-exist happily with agriculture and grazing operations.

A range of health claims are made against wind turbines, including disrupted sleep and annoyance to some individuals who live within close proximity to wind farms. This paper found there is no credible evidence directly linking exposure to wind turbines with any negative health effects. Available evidence suggests the health effects of wind turbines are strongly mediated by subjective factors. For example, health effects appear to be lessened in community-owned operations where locals benefit directly from the existence of turbines. Perceived high levels of opposition to wind farms on health grounds have been linked to a vocal minority of people.

Australia is not realising its wind energy potential and is currently generating far less energy from wind power than many European countries. The advantages of increasing our wind power are great, with wind having the lowest health, environment and climate impact of any energy source available.

[1] Results are drawn from an online poll taken by the Australia Institute in August 2014 (n=1410).

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Executive summary

Wind power represents one of the most climate, health and environmentally friendly choices of all energy production. Wind energy also does not create the same competition for resources like land and water as many other energy sources, and has minimal effect on biodiversity in comparison with unconventional gas and coal. Although there is some impact on avian life (birds and bats) that is of concern, this is significantly less than other sources of death and injury—including predicted impacts from climate change—and much lower in Australia than in some overseas operations. Australia has some of the best wind resources in the world, however it is currently generating far less wind power (by volume and per capita) than many European countries.[1]

Although wind generated power faces limitations and impacts on the well-being of some, it represents the lowest impact energy source currently available in Australia. Yet wind farms have faced considerable controversy and public scrutiny, in large part due to claims that wind turbine noise causes ill-health for those living within close proximity. However some reviews have found that there are no direct ill-health effects attributable to wind turbines (including from audible and sub-audible sound, visual impacts or electromagnetic frequency)[2], especially at the set-back distances and sound restrictions found in Australia.

The evidence considered in this report shows that there is a correlation between proximity to wind farms, disrupted sleep and annoyance in some individuals to an extent that compromises quality of life. However it is unclear whether these represent direct effects or are mediated by attitudes towards wind farms. Although noise from wind turbines is likely to be experienced as more annoying than other sounds, at the levels found in Australian operations such effects are likely to be highly influenced by subjective factors, which has consequences for how they are mitigated and weighed against other costs and benefits. It also appears that such effects are lessened in community owned operations where locals benefit directly from the existence of turbines.

Key findings

- Australia has some of the best wind resources in the world. While its use is limited by its variability and current energy infrastructure, it has been estimated that wind could generate up to 40 per cent of Australia's electricity needs
- Wind is one of the least GHG intensive energy sources, even taking into account life-cycle emissions from other energy sources used in developments
- Several reviews have found no credible evidence directly linking exposures to wind turbines to any negative health effects
- Proximity to wind turbines has been associated with annoyance and sleep disturbance in several studies, with the character of wind turbine noise potentially making it more annoying than other sounds
- Many studies indicating effects on sleep and general wellbeing are at sound levels greater than those found in Australia, or at closer distances than Australian wind farms
- Evidence suggests that ill-effects are strongly mediated by subjective factors—especially attitudes towards the visual impact of turbines
- Studies on 'wind-turbine syndrome' and 'vibro-acoustic disease' are seriously flawed, and there is no credible evidence for these conditions being caused by wind turbines
- Perceived high levels of opposition have been linked to a vocal minority, with many surveys suggesting reasonably high levels of support, especially in community owned wind operations
- Wind turbines do cause bird and bat deaths, however rates are well below deaths from many other causes including climate change, and technological advances are likely to mediate these further
- Environmental impacts from wind farms are minimal and they can co-exist with agriculture and grazing
- Comparatively, wind energy has the lowest health, environment and climate impact of any energy source

1. Introduction

The latest Intergovernmental Panel on Climate Change (IPCC) report on climate change noted that over two-thirds of the 'carbon budget' allowable in order to avoid dangerous climate change has already been spent. In a business-as-usual scenario, the remaining budget would be spent within 25 years.[3] Although fossil fuel companies continue to invest and expand apace, the growing recognition that current energy practices are unsustainable has generated substantial interest in various forms of renewable energy.

Concerns about impacts on health have hampered development of wind resources in Australia. In particular, fears over the potential health effects of noise, along with the visual impact of wind farms, and damage to fauna have found voice in the public domain.

The purpose of this report is to provide a narrative summary of the literature that exists on these health and environmental concerns, putting these impacts in a comparative framework with other sources of energy generation. This report does not address economic considerations or technical limitations in any detail, except as their perception directly impacts on the social acceptance of wind developments.

2. Overview

2.1 Wind energy worldwide

While electricity from wind only represents a small fraction of current world electricity production with an estimated capacity of 3.3 per cent in 2012, it is also the fastest growing energy source.[1]

Germany, the US, Spain, India and China are currently the major wind energy producers by volume, while Denmark, Ireland, Spain and Portugal lead in terms of percentage of national electricity. [1]

The biggest obstacle to using wind as a major energy source is its variability. While this limits the extent to which wind power can play a role as a primary energy source, they can be offset in various ways such as interconnection to other energy sources, storage of electric power, and improved forecasting for planning.[4]

2.2 Wind energy in Australia

Australia has some of the world's best sources of wind energy, concentrated around coastal areas but extending several hundreds of kilometres inland, especially in Southwest Western Australia, southeast South Australia, western Victoria, northern Tasmania and some elevated areas in NSW and Queensland (see figure 1). At the end of 2012, Australia's wind generation was 7,700 GWh approximately 3.4 per cent of total electricity demand.[1]

While renewable energy still represents a small slice of the energy market, growth would be further encouraged by policies aimed at reducing emissions and establishing renewable energy targets such as The Clean Energy Future Plan and the Renewable Energy Target, with wind anticipated to represent the vast majority of the expected growth in Australia's renewable energy[5] (although these schemes are uncertain under the current government).

While the fluctuating nature of wind makes it impracticable as a sole energy source, it has been estimated that it could provide up to 40 per cent of Australia's total on-grid electricity needs if various strategies were employed to mitigate its unstable nature and overall energy consumption were reduced.[4]

Figure 1: Australia's wind resources. Source: Windlab Systems Pty Ltd, DEWHA Renewable Energy Atlas; Geoscience Australia

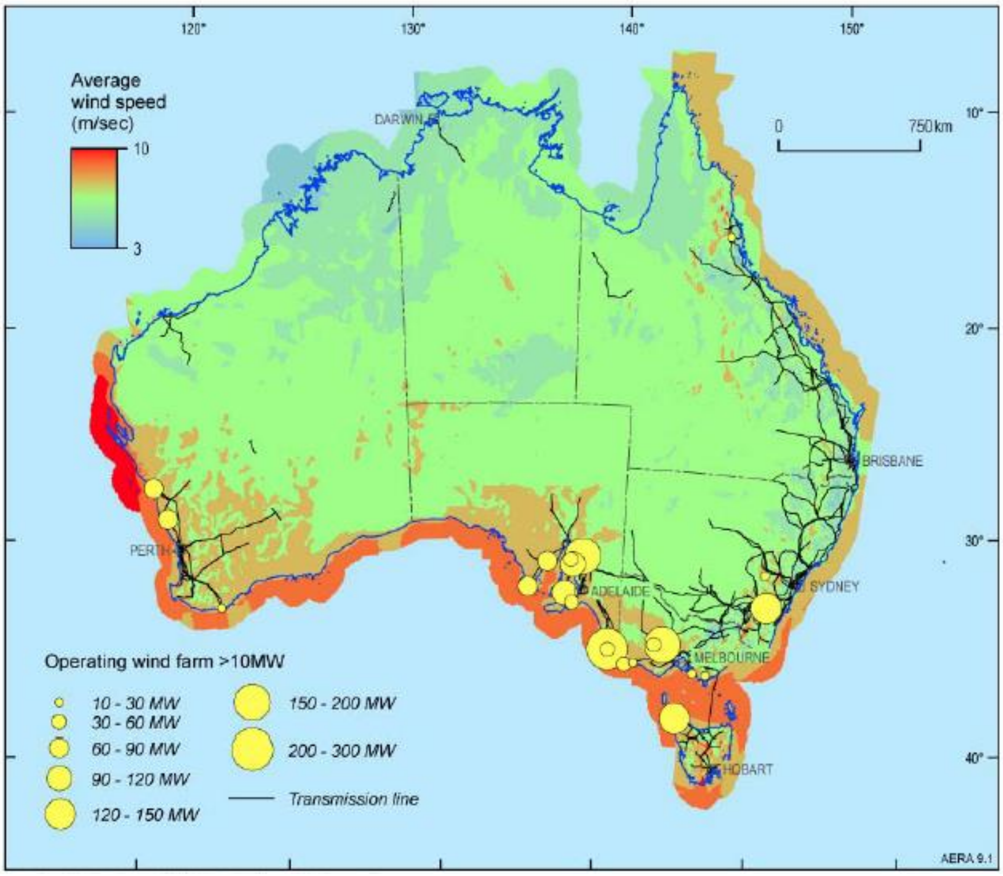
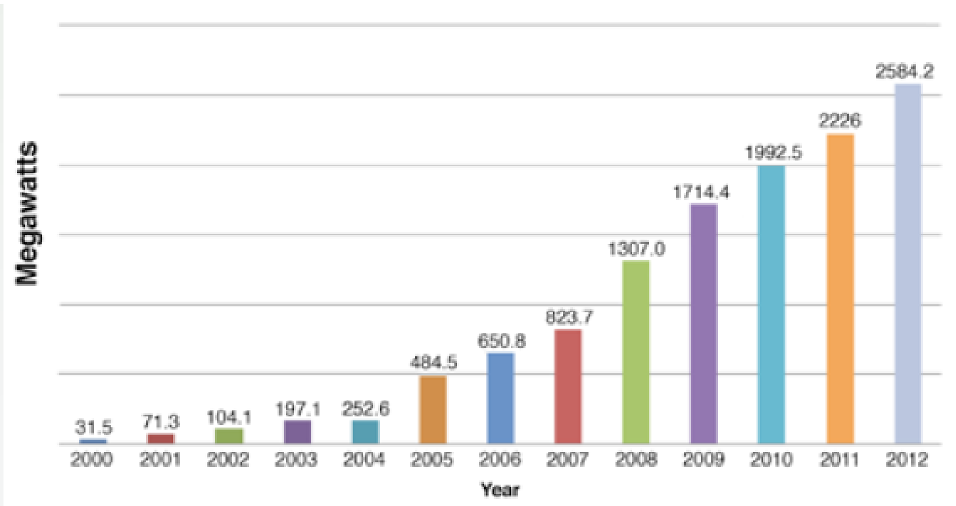


Figure 2: Cumulative installed wind capacity 2000-2012. Source: International Energy Agency



The regulations governing wind farms in Australia are amongst the strictest in the world, with some groups claiming that these hamper the development of the industry, especially in Victoria and NSW.[6] Current setback distances from residences are 2km in Victoria and NSW, and 1km in SA, while noise restrictions in Australia restrict sound levels from wind turbines to about 35-40dBA near residential areas.[7,8,9] In Victoria, residents within 2km of any planned wind farm have the right of veto, and there are several 'no-go' zones where wind developments are blocked, including but not limited to national parks.[8]

2.3 Impacts of wind energy

While wind is one of the cleanest energy sources from the perspective of the climate, concerns over the health effects of wind turbine noise and their impact on visual amenity have attracted considerable attention. However, the perception of opposition may have been skewed by a vocal minority, and many of the claimed health impacts have a strong subjective basis that needs to be weighed against the objective evidence and against the benefits that wind energy can generate for the climate and ultimately health.

2.3.1 Climate

One of the greatest benefits of wind power is its extremely low GHG impact, which is estimated to be lower than any other current energy generation technology (with the possible exception of hydroelectricity).[10,11] However, while wind energy does not produce any GHG emissions directly, it is responsible for some emissions during the life-cycle of wind infrastructure as a result of the use of GHG emitting energy sources in the production of materials and infrastructure, considered in Section 3.

2.3.2 Health

Health concerns over wind farms have tended to focus on potential impacts of noise exposure—audible noise, infrasound and low-frequency sound (LFN). There are also other health concerns associated with the visual impact of wind farms and electromagnetic fields (EMF), as well as potential indirect health consequences from environmental impacts such as resource conflict and impacts on biodiversity.

As with all energy sources, the potential health and environmental impacts vary considerably depending on the details of individual operations. Important factors include the local environmental and regulatory context, and the degree of community involvement.

While noise associated with wind turbines can cause annoyance and has been correlated with sleep disruption[12-15], the potentially greater concern is the psychological stress caused by perceived threats and attitudes towards wind farms, which can amplify negative impacts from noise and visual exposures.[16-19] There is a very minor level of uncertainty regarding the impact of infrasound and LFN[20], however an analysis of the peer-reviewed literature indicates that claims about wind turbine syndrome and vibro-acoustic disease are unsubstantiated and any symptoms are highly likely to be 'nocebo' effects.

Wind farms require considerable amounts of land, and they can pose a risk to avian life. More reliable modeling has provided a reasonably accurate estimate of bird mortality and suggests ways to reduce these consequences, which are more minimal than often considered. However, unlike many other forms of energy generation, wind farms tend to work harmoniously with grazing and other forms of land-use, and do not greatly disrupt biodiversity.

2.3.3 Benefits

There are considerable benefits that need to be taken into account when assessing the overall impact of wind farms, especially when considered in the context of the health impacts of current technologies. The most striking of these is its potential impact on climate change. The WHO has estimated that climate change already causes over 150,000 deaths annually, with evidence that "unmitigated greenhouse gas emissions would increase disease burdens in the coming decades", especially for the poorest populations.[21] Wind energy is currently estimated to help Australia cut its GHG emissions by nearly 3,256,000 tonnes each year[22], and increasing wind energy could substantially reduce Australia's contribution to GHG emissions.

3. Greenhouse gas emissions

Energy produced from wind is among the most climate-friendly of current energy generation technologies, however the production and maintenance of turbines does create some emissions. The emissions that are attributed to wind power are associated with the conventional energy sources that are used in the construction and maintenance of facilities—wind itself is not responsible for any emissions directly.

Although estimates vary, a compilation of information from 11 sources reported measurements of between 6 – 124 tonnes of CO2e/GWh, with the World Energy Council giving a range of 7 – 24kg CO2/MWh.[23] This is amongst the lowest of currently available technologies (see figure 3).[24]

Figure 3: Comparison of estimated lifecycle GHG emissions from different energy sources. Source: World Nuclear Association 2012

Technology	Mean	Low	High
	tonnes CO_2e/GWh		
Lignite	**1,054**	790	1,372
Coal	**888**	756	1,310
Oil	**733**	547	935
Natural Gas	**499**	362	891
Solar PV	**85**	13	731
Biomass	**45**	10	101
Nuclear	**29**	2	130
Hydroelectric	**26**	2	237
Wind	**26**	6	124

4. Health

More than any other form of energy generation, the health implications of wind are often indirect and dependent on subjective factors. Some recent reviews of available evidence have found that there is "no credible peer reviewed scientific evidence that demonstrates a direct causal link between wind turbines and adverse physiological health impacts in people".[25,26] However, there is some connection between wind turbines, annoyance and sleep disturbance.[12-15]

It is apparent that attitudes towards wind farms have a considerable influence on the extent to which noise, visual disruption and social change resulting from wind farms cause stress or annoyance, which in turn can contribute to other health issues. Any health effects from such exposures are therefore likely to vary considerably across communities and are best considered as *indirect* effects.

4.1 Noise

The possible health impact of audible and infrasound from wind turbines has attracted considerable attention. Apart from its potential to directly impact health through hearing loss and tinnitus, it is well established that noise can influence health through pathways including sleep disturbance, stress, and decreased cognitive ability.[27] In extreme cases, these indirect pathways can lead to illnesses such as cardiovascular disease, decreased immune function, endocrine disorders and mental illness. In and of itself, annoyance can represent a significant degradation in quality of life.[13, 27]

The noise exposure levels from Australian operations are highly unlikely to directly cause any significant issues. The National Health and Medical Research Council (NHMRC) recently conducted an independent systematic review of the existing scientific literature on the connection between wind farms and health, with only 7 studies meeting their inclusion criteria. On the basis of these studies together with background information about proposed pathways, they concluded that: “with the exception of annoyance, sleep quality or disturbance and quality of life—which are possibly related — there was no consistent association between adverse health effects and estimated noise from wind turbines” (NHMRC 2013 p 169).[2]

Although the findings in this report largely support the NHMRC’s findings, although considers a broader range of evidence and provides more discussion of the importance of considering subjective factors and remaining uncertainties regarding LFN.

4.1.1 Measuring sound

Sound is measured as sound pressure using decibels (dB), and as frequency (or pitch) measured in hertz (Hz).27 Measurements relating to wind turbines are usually given in dBA, where ‘A’ refers to a weighting based on differences in sound discernible by the human ear. The threshold of human hearing is approximately 0 – 130 dB, with an increase of 10dB(A) usually experienced as a doubling in loudness (see table 1 below).

Table 1: Source: State Government of Victoria, Department of Health

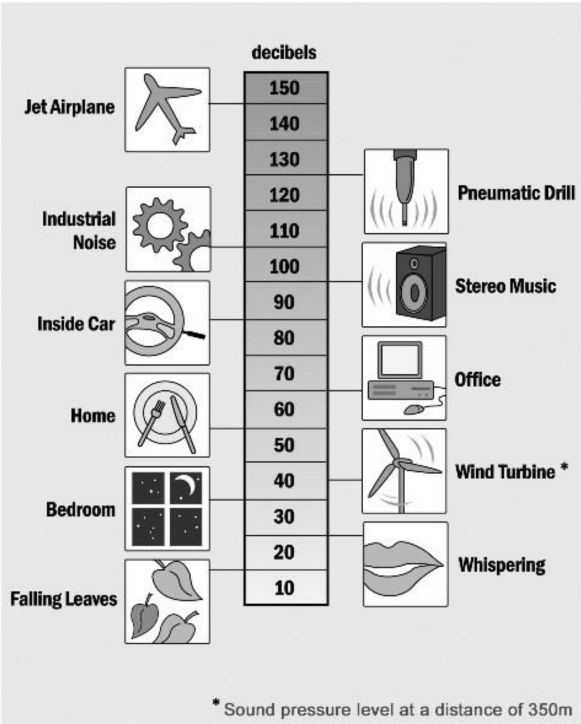
Increase in sound level (dB)	Change in loudness (subjective)	Example
1	Imperceptible	31 dB does not sound louder than 30 dB
3	Just perceptible	33 dB sounds just louder than 30 dB
5	Clearly noticeable	35 dB sounds clearly louder than 30 dB
10	Twice as loud	40 dB sounds twice as loud as 30 dB
20	Four times as loud	50 dB sounds four times louder 30 dB

Another common measurement is LAeq. This is “the constant sound level that, in a given time period, would convey the same sound energy as the actual time varying sound level, weighted to approximate the response of the human ear”.[28]

There are several different estimates of sound levels from Australian wind farms, however a 10-turbine wind farm at 350m produces approximately 35-45 dB(A).[29] Guidelines in NSW and SA limit noise to 35 dB(A) at the location of those exposed in localities “which are primarily intended for rural living” and 40 dB(A) in other localities, or to less than 5 dB(A) higher than the background noise (whichever is greater).[20] WA guidelines suggest 35dB(A) or levels not exceeding the background noise level by more than 5dB(A), whichever is greater.[21] These levels can be compared with other sound sources in figure 3 below.

It should also be noted that houses attenuate sound by approximately 15-20 dB—so, for example, sound inside a bedroom is likely to be 15-20 dB quieter than that measured outside. It has also been noted that the presence of vegetation barriers can further dampen noise.[30]

Figure 4: Comparison sound levels. Source: American Wind Energy Association



4.1.2 Health implications of noise

There are many factors that determine how sound is experienced, including cumulative properties, temporal patterns (duration and fluctuation), the psychological state and susceptibility of the individual, and difference to ambient noise levels.

While the WHO notes that "we do not completely understand all of the complex links between noise characteristics and the resulting effects on people"[27], they provide guideline values that indicate the levels at which noise might be expected to affect functioning (see table 2 below)—for example, sleep disturbance is associated with continuous noise of 30 dB per hour, or 45 dB for an intermittent event. While the WHO do not give guidelines for noise and mental illness, effects on cognitive performance, or behavioural effects, there is evidence that long-term exposure to major noise sources (such as aircraft) or exposure to noise over 80 dBA can have such effects.

Annoyance levels are highly variable across individuals, though some characteristics of noise—such as being accompanied by vibration, containing low frequency components or impulses, or increasing over time—tend to make it more annoying. The effects of noise may be magnified in vulnerable groups including the elderly, ill, depressed, hearing impaired, babies and young children, and those dealing with complex cognitive tasks.[27]

Table 2: WHO guideline values for community noise. Source: Berglund et al 1995

Specific environment	Critical health effect(s)	LAeq [dB]	Time base [hours]	LAmax, fast [dB]
Outdoor living area	Serious annoyance, daytime and evening Moderate annoyance, daytime and evening	55 50	16 16	- -
Dwelling, indoors	Speech intelligibility and moderate annoyance, daytime and evening	35	16	
Inside bedrooms	Sleep disturbance, night-time	30	8	45
Outside bedrooms	Sleep disturbance, window open (outdoor values)	45	8	60
School class rooms and pre-schools, indoors	Speech intelligibility, disturbance of information extraction, message communication	35	during class	-
Pre-school Bedrooms, indoors	Sleep disturbance	30	sleeping -time	45
School, playground outdoor	Annoyance (external source)	55	during play	-
Hospital, ward rooms, indoors	Sleep disturbance, night-time Sleep disturbance, daytime and evenings	30 30	8 16	40 -
Hospitals, treatment rooms, indoors	Interference with rest and recovery	#1		
Industrial, commercial, shopping and traffic areas, indoors and Outdoors	Hearing impairment	70	24	110
Ceremonies, festivals and entertainment events	Hearing impairment (patrons:<5 times/year)	100	4	110
Public addresses, indoors and outdoors	Hearing impairment	85	1	110
Music through headphones/ Earphones	Hearing impairment (free-field value)	85 #4	1	110
Impulse sounds from toys, fireworks and firearms	Hearing impairment (adults) Hearing impairment (children)	- -	- -	140 #2 120 #2
Outdoors in parkland and conservation areas	Disruption of tranquillity	#3		

#1: as low as possible;
#2: peak sound pressure (not LAmax, fast), measured 100 mm from the ear;
#3: existing quiet outdoor areas should be preserved and the ratio of intruding noise to natural background sound should be kept low;
#4: under headphones, adapted to free-field values

4.1.3 Audible noise

Wind turbines generate audible noise from the turbine gearbox, the generator and the movement of blades. Because the audible sound levels produced by wind turbines are low, it is not always clear whether annoyance, stress and sleep disturbance should be considered as a direct or indirect effect. Both interpretations are considered below.

The restriction of sound levels to 35 - 40 dB(A) in Australia means that wind farm noise falls well below the range associated with nearly all direct and/or serious health implications, but within a range that could potentially cause annoyance. This is reflected in the conclusions of the NHMRC systematic review that there is no evidence to support the claim that there are any direct pathological effects from wind farms, and any potential impact on humans can be minimised by following existing planning guidelines.[2]

However, such sound levels are noticeable: one study found that the amount of people noticing wind farm noise increased "almost linearly" with increasing sound pressure, with 5-15 per cent noticing it at 29 dB(A), and 45-90 per cent noting it at 41 dB(A), with levels above 37 dB(A) marking a clear increase in those finding the noise annoying, from about 5 per cent of people in the range 29-37 dB(A) up to 30 per cent at 41 dB(A) (over the guideline limits for Australian wind farms).[12]

Annoyance in and of itself can be detrimental to quality of life, and there is some evidence that the characteristics of wind turbine sound can make it more annoying than other sounds at the same level. Wind speed and direction, the model, size and arrangement of turbines, and the topography of the landscape can all affect the type of sound produced.[24] One study found that "[s]wishing, whistling, resounding and pulsating/throbbing were the sound characteristics…most highly correlated with annoyance"[12], with other studies also finding that swooshing modulations associated with wind turbines are a particular source of annoyance.[31,32] Noise-induced rattle, which occurs over 45 dB(A) is also known to increase annoyance.[33] A detailed US study noted evidence that wind turbine noise is "more noticeable, annoying and disturbing than other community or industrial sounds at the same level of loudness"[13], and that its fluctuating character and occurrence at night are particularly annoying. The authors also found that a "small number of epidemiological studies have linked wind turbine noise to increased annoyance, feelings of stress and irritation, sleep disturbance, and decreased quality of life"[13], however it was noted that this was more likely when wind turbine noise *exceeded* 35-40 dB(A)—again, over the range stipulated for Australian wind farms.

Along with annoyance, sleep disturbance is the most commonly associated negative effect of wind farms. This can refer to both being woken up, and finding it difficult to go back to sleep. The level of sound that the WHO associate with sleep disturbance is 30dB *inside* the bedroom, which is above the level that would be expected with restrictions of 35-40dB(A) readings outside residential properties. However, it is possible that models predicting wind turbine noise may underestimate night time exposures for several reasons, such as the 'van den Berg effect'—resulting in a 'thumping' noise which seems to occur in particular on cold, still nights[30,34]—and reduced levels of background noise which can make wind turbine noise more noticeable at night. Such factors led the authors of one report to suggest that predicted levels of 40 dB(A) are enough to disturb sleep.[35]

Sleep disturbance was reported in a series of well-designed studies carried out in Sweden and Denmark, with "[s]ixteen per cent of surveyed respondents who lived where calculated outdoor turbine noise exposures exceeded 35 dB LAeq…[reporting] disturbed sleep".[12] Increasing levels of sleep disturbance with higher noise levels was found in a meta-analysis of three European datasets[14]; a US study found that participants living within 1.5km of wind farms had worse self-reported sleep and mental health than those living 3-7km away with a "clear and significant dose-response relationship" (also noting that the degree of effect "seems to be greater than that of other sources of environmental noise")[28]; and a survey of NZ residents living less than 2km from wind turbines reported widespread sleep disturbance, with the authors taking these findings to reinforce previous studies "suggesting that the acoustic characteristics of turbine noise are well suited to disturb the sleep of exposed individuals".[36] It is important to note that many of these studies reported on exposures for those inside the 2km set-backs currently enforced for Victorian operations.

Annoyance and sleep disturbance can be detrimental to general well-being, as captured in measurements of health related quality of life (HRQOL). One study employed questionnaires (with their purpose masked) to look at the association between HRQOL measurements and proximity to an industrial wind farm in a semi-rural area. This compared measurements of those in proximity to a wind farm (with typical noise exposures ranging from 24 dB(A) to 54 dB(A)), to a socioeconomically matched group in an area without a wind farm.[36] The study found that the turbine group reported “lower amenity than the comparison group”, and also lower sleep satisfaction ratings.

Annoyance, stress and sleep disturbance can also lead to further health implications, including for mental health—for example a Canadian study looking at perceived effects of wind turbine noise using a self-reporting survey found that 72 per cent of participants reported increased symptoms of anxiety, stress and depression[37], and other studies finding annoyance in relation to wind farms is connected to feelings of tension, stress, irritability, headaches and ‘undue tiredness’.[38] Although direct correlations between noise exposure and health effects such as high blood pressure only occur with exposure to greater noise levels (55- 60dB), these health effects are also correlated with stress resulting from sleep disturbance and annoyance.[35] Because of these links, annoyance can be:

> *[V]iewed as a measurable indicator of enhanced risk for chronic imbalance in the physiological stress system; an imbalance that could lead to more severe states, such as high blood pressure, and if prolonged, to cardiovascular diseases.*[39]

Although direct connections between wind turbine sound and poor health cannot be drawn, the potential for annoyance and sleep deprivation to lead to other health complications needs to be considered.

4.1.4 Subjective factors influencing noise impacts

Despite the correlation of wind farms with sleep disturbance in some cases, it is likely that not all reported cases of sleep disturbance are directly caused by wind turbines. For example, generally poor sleepers may attribute sleep disruption to wind turbines when these were not the direct cause[39], and subjective factors such as attitudes towards wind farms, general sensitivity, expectations regarding sound levels, and aesthetic and other values seem to play a fundamental role in experiences of stress and annoyance in relation to wind turbines.

The significant role played by such subjective factors suggests that in very many cases (especially where noise is lower than 40 dB(A)) annoyance, stress and sleep disturbance might better understood as an *indirect* effect rather than directly caused by exposure to wind turbine noise (although several studies stress the presence of a dose-response relationship that might support a more objective interpretation).

This is highlighted in a review that considered both peer-reviewed literature and popular on-line sources. The authors found that, although both sources conclude that wind turbines can be the source of annoyance and sleep disturbance (especially at levels greater than 40db(A)), they differed in their attribution of the cause. While popular material tended to draw a direct causal link, peer reviewed studies showed annoyance to be “more strongly related to visual impact, attitude to wind turbines and sensitivity to noise”, with “no peer reviewed articles demonstrat[ing] a direct causal link between people living in proximity to modern wind turbines, the noise they emit and resulting physiological health effects”.[26]

The studies conducted in Sweden and Denmark clearly illustrate the role played by attitudes towards wind farms, and the caution needed in drawing conclusions about the causes of negative health effects.[12,39,38,40] While acknowledging that characteristics of the noise itself may be a factor, the authors also note that levels of annoyance are closely correlated with self-reported attitudes towards wind-farms. A separate small qualitative study found that the respondents who found the noise (at levels of 32 – 40 dB) of wind turbines in their vicinity annoying tended to perceive the turbines as an intrusion of their privacy that conflicted with personal values, and felt that they lacked control over the decision to have wind turbines, viewing them as an injustice.[41] It also appears that noise in quiet rural areas where “there is a greater expectation for and value placed on peace and quiet" will be experienced as more annoying and result in more sleep disturbance.[33,39]

Some of these studies highlighted the close ties between annoyance and attitudes towards the *visual* impact of wind farms. This seemed to influence the perception of noise even when turbines were not visible at the time of the noise exposure, suggesting that the effect was not due to visual input altering the experience of noise, but was primarily an evaluative response.[40] Furthermore, where the turbines were visible but their noise was masked by background noises (such as when they were placed next to a motorway), general annoyance remained the same. The authors also note that expectations regarding the environment (for example, expectations of rural peace) and the perceived disruption to the restorative effects of quiet and natural beauty also influenced how annoying wind turbine noise was.[40]

In one analysis, the relation between turbine noise and stress was interpreted in terms of cognitive stress theory, whereby "an individual appraises an environmental stressor, such as noise, as beneficial or not, and behaves accordingly".[39] However, it was also acknowledged that the findings are consistent with causation running in the other direction—from annoyance to negative attitudes towards wind farms—or in a feedback loop between annoyance and attitude.[33,39]

The fact that stress, annoyance, and sleep disturbance seem to be strongly determined by subjective factors has consequences for their management and how they might be weighed against other kinds of health effects. In some cases, it means that they cannot easily be addressed—for instance "it is not clear that for this hypersensitive annoyed population that any set back distance could mitigate the indirect effects".[26] However, the role played by visual impact in particular also suggests that attempts to lessen negative impacts should focus on this factor. The effects of exposure to misinformation and the manipulation of fears highlights the role of communication and education. In general, the subjective aspect of such effects also supports claims that community owned wind farms where there is a high degree of community consultation and involvement meet with less opposition and are responsible for less indirect health effects.

While audible noise can have some impact on quality of life, the relatively small number of people affected by these issues compared with the health implications of other energy sources such as fossil fuels also needs to be kept in mind, and will be discussed in more detail in section 4.7.

4.1.5 Low frequency and infrasound

Perhaps the most widely publicised claims associated with wind turbine noise are those concerning the health effects of 'infrasound' (sound under 20Hz, mostly below the level of human perception) and LFN (20–200 Hz). This includes what is sometimes characterized as 'wind turbine syndrome'—a cluster of symptoms including dizziness, headaches and insomnia.

Infrasound is generated by many natural and artificial sources such as vehicles, aircraft, air-conditioning units, waves, and sounds generated inside the body like coughing and heartbeat.[27,42] There is some evidence that humans process infrasound differently from other sound, which "raises the possibility that exposure to the infrasound component of wind turbine noise could influence the physiology of the ear" [42], however little is known about these physiological changes and it seems highly unlikely that levels of LFN and infrasound exposures from wind turbines could cause health harm.[2,43]

There remains some debate over the levels of infrasound and LFN generated by wind turbines, with several technical difficulties accompanying attempts to measure infrasound and estimate its effects, largely because it requires much more sophisticated equipment than the measurement of audible noise. Some studies claim they generate high levels (between 90-100 dB) of sound in the range of 1-2 Hz[42], with this low-frequency noise component given as one reason why wind turbines are more annoying than other sounds.[44] Unlike audible noise, LFN can also be emphasized indoors (or at least is not "attenuated" in the same way as higher frequencies).[33] However, it has been convincingly argued that these measurements are uncharacteristic of exposure in residential buildings, and that exposure to LFN is not likely to be "higher than what many people are exposed to daily, in the subway and buses or at the workplace".[35]

The rapid review of evidence conducted by the NHMRC cited numerous reports concluding that there is no evidence of health effects arising from infrasound or low frequency noise generated by wind turbines[45], while their systematic review concluded that their were too few studies of relevance to claim that LFN from wind turbines could affect health.[2] This is echoed in another review, which states that "most literature dealing with the subject indicates that infrasonic noise below the threshold of hearing will have no effect on health", although the authors also note that there are "variations in individual sensitivities".[44] A further review concluded that, although infrasound is not expected to cause any health issues, because of public concern and the fact that there are some aspects of infrasound that are "not unanimously accepted by all technical and medical practitioners", further measurement and monitoring are warranted.[46] A further review similarly came to the conclusion that "the effects of infrasound require further investigation", as there was some evidence that infrasound could have physiological effects on the ear.[47]

A comprehensive report on LFN and the possible effects associated with it found that it can cause "extreme distress to a number of people who are sensitive to its effects", although there is "little or no agreement about the biological activity following exposure", and such effects are only found at high levels that are not associated with wind turbines.[43] A consideration of community noise standards has suggested that noise limits should be set to 30dBA when the source contains considerable amounts of LFN.[30]

The most comprehensive report identified on LFN was based on a systematic literature review together with discussions with experts.[35] Among the effects of LFN, they note that:

> *[L]oudness and annoyance of infrasound and…LFN…increases more rapidly with increasing sound pressure level than sounds of higher frequencies [and]….Prolonged exposure to audible low frequency sounds may cause fatigue, headache, impaired concentration, sleep disturbance and physiological stress, as indicated by increased levels of saliva cortisol.*

However, the report also noted that a comparison of LFN from wind turbines at guideline values of 40 dB compared to road traffic noise at guideline values of 55 dB showed permitted noise from wind turbines to be "lower for all frequencies above 20 Hz" —that is, there is no indication that risks from LFN from wind farms would be any greater than from normal levels of traffic.[35]

Another detailed report noted that LFN in modern turbines is produced at low levels (50 – 70 dB below 20 Hz), and it is the *audible* 'swishing' component of wind turbines that is more problematic. This report also noted the misleading nature of reporting about LFN and wind turbines, causing unnecessary fear that may enhance subjective impacts of wind farms.[47]

While there is a degree of uncertainty surrounding both the levels of infrasound from wind turbines and their effects, it appears unlikely that wind turbines at the sound levels and setback distances found in Australia would have any substantial health implications.

4.1.6 'Wind turbine syndrome' and vibro-acoustic disease

Given their prominence in the public debate, it is worth briefly considering two specific syndromes that have been attributed to LFN from wind farms—wind turbine syndrome and vibro-acoustic disease.

The term 'wind-turbine syndrome' was coined in a non-peer-reviewed, self-published book based on self-reported symptoms from 10 families living near wind turbines.[48] These symptoms included sleep disturbance, headache, tinnitus (ringing in the ears), ear pressure, dizziness, vertigo, nausea, visual blurring, tachycardia (rapid heart rate), irritability, problems with concentration and memory and panic episodes, which the author attributed to exposure to LFN and vibrations from turbines:

> *Wind Turbine Syndrome, I propose, is mediated by the vestibular system—by disturbed sensory input to eyes, inner ears, and stretch and pressure receptors in a variety of body locations. These feed back neurologically onto a person's sense of position and motion in space, which is in turn connected in multiple ways to brain functions as disparate as spatial memory and anxiety. Several lines of evidence suggest that the amplitude (power or intensity) of low frequency noise and vibration needed to create these effects may be even lower than the auditory threshold at the same low frequencies.*[48]

The serious flaws in this study have been pointed out by a number of authors, including the fact that questionnaires did not disguise the intent of the study; the existence of potential bias in the selection of the study participants; the small size of the study; the lack of noise measurements; and the lack of adequate statistical representation of potential health effects.[25,26]

'Vibro-acoustic disease' (VAD) is described as a 'whole-body, multi-system' pathology occurring in people with long-term exposure to loud sound (greater than or equal to 90 dB) and low frequency noise (less than or equal to 500 Hz), with symptoms ranging from infections of the respiratory tract, hearing impairment, neurovascular disorders, myocardial infarction, epilepsy, psychiatric conditions, and attempted suicide.[49] The disease has not gained clinical recognition, but the authors claim that there is evidence for its existence in aircraft engineers.

It has been pointed out that nearly all published papers on VAD had a first-author belonging to the same research group, and 74 per cent of citations were self-citations.[50] There have been no published, peer-reviewed articles connecting the purported disease to exposure from wind turbines, however a conference paper claimed that research results "irrefutably demonstrate that wind turbines in the proximity of residential areas produce acoustical environments that can lead to the development of VAD (vibroacoustic disease) in nearby home- dwellers". This claim was seemingly based on one child living in close proximity to wind turbines who had "memory and attention skill" problems in school and "tiredness" during physical education activities.[51] An analysis of the claims noted that no other explanation was proposed, and that no details from the members of other houses within the same proximity were discussed. The study was evaluated as being of "abject methodological quality, failing the most elementary tests of epidemiological investigation".[50]

Aside from flaws in study design and reporting, the claims made concerning wind turbine syndrome and VAD also contradict the findings of the studies discussed previously which found no consistent associations between symptoms such as headaches, tinnitus, chronic disease and undue tiredness and exposure to noise from wind turbine.[39]

4.1.7 Evidence for 'nocebo' effect

Apart from issues with the studies purporting to demonstrate the existence of wind-turbine syndrome and VAD, there is also some evidence that such symptoms could be a 'nocebo' effect—a result of expectations of harm rather than exposure to infrasound. A recent study used a 'sham-controlled double-blind provocation study'[52], randomly assigning participants to different 'expectancy' groups, providing them with information (readily available from the internet) that would set up high or low expectations that infrasound caused specific symptoms associated with wind turbine syndrome. Participants were then exposed to 10 minutes of either infrasound or sham infrasound. The authors found that the high-expectancy group "reported significant increases, from pre-exposure assessment, in the number and intensity of symptoms experienced during exposure to both infrasound and sham infrasound", while there were "no symptomatic changes in the low-expectancy group", concluding that "[r]esults suggest psychological expectations could explain the link between wind turbine exposure and health complaints".[52]

Another report looked at the timing of complaints about wind turbines and wind turbine syndrome, and found that the clear majority of noise and health complaints have occurred after the widespread efforts of anti-wind farm lobby groups.[53]

4.2 Electromagnetic fields

The potential for electromagnetic fields (EMF—also referred to as 'electrical pollution' and electromagnetic radiation or EMR) from wind turbines to impact on health has not been reported in any peer-reviewed literature but appears in some popular sources. EMF is found wherever there is an electricity source, including any wire carrying electricity. The NHMRC rapid review unequivocally states that the "electromagnetic fields produced by the generation and export of electricity from a wind farm do not pose a threat to public health…The closeness of the electrical cables between wind turbine generators to each other, and shielding with metal armour effectively eliminate any EMF"[45], while their systematic review noted the lack of information available but noted that available data suggests the range of EMF/EMR is likely to be similar to household appliances.[2]

4.3 Visual impact

The visual impact of wind farms is a central reason for opposition to some developments, and, as discussed previously, visual exposure and attitudes towards the aesthetics of wind farms has a strong influence on other impacts.

Aside from aesthetic considerations, there have also been claims that visual effects—such as shadow flicker—can directly influence health.

4.3.1 Shadow flicker and blade glint

Shadow flicker refers to the pattern of alternating light intensity resulting from the shadows cast by rotating turbine blades. Such shadows can be cast across considerable distances when the light source is low on the horizon, and can be concentrated when cast over an open door or window. The extent of flicker depends on factors such as distance to the turbines and their rotational speed, the strength of the sun, and the presence of screening. Blade glint refers to bright light reflected from blades, which could potentially be experienced as a strobe-like effect by observers.

Planning guidelines in Australia restrict the amount of shadow flicker allowable—for instance, in Victoria this is restricted to 30 hours per annum[8] which is a typical upper level of exposure from operating wind farms.[26] Apart from some people finding shadow flicker annoying, there is little evidence that there are any further health effects. A review of evidence noted two studies that looked at the relationship between photosensitive epilepsy and shadow flicker. While suggesting that flicker “at frequencies greater than 3 Hz pose a potential risk of inducing photosensitive seizures in 1.7 people per 100,000 of the photosensitive population”, the study notes that the blade rpm that this translates to is well above that found in normal large wind farms.[26]

The risk of blade glint from modern wind turbines is considered to be very low.[45] The use of non-reflective paint, the varying orientation of turbines, the concave surfaces of blades, and the fact that such an effect only occurs under certain light conditions make it unlikely, and no studies were found that connected it to any health implications.

4.3.2 Visual amenity

The visual impact of wind farms is one of the most common reasons given for opposing them, with a media analysis of newspaper reports finding that landscape change and visual amenity impacts (followed by noise and poor consultation) were the most commonly cited reason for opposing wind farms.[30] A poll in the US (where the majority of respondents supported wind energy) found that its opponents “focused on aesthetics in particular”.[54]

Wind farms in Australia are often highly visible because of their location on high coastal terrain.[55] Apart from the turbines themselves, the associated infrastructure can also have a visual impact.[30]

However, while responses to the general visual impact of wind farms vary considerably, there are several polls suggesting that the majority of people do not find them unsightly. A Victorian poll found that 97 per cent of respondents described wind turbines as ‘interesting’, and 74 per cent as ‘graceful’[56], while a Scottish poll found that “twice as many people think that their local wind farm has had a positive impact on the landscape as think it has had a negative impact.[57] Visual impact can also be mitigated by the way in which wind turbines are laid out, and the number of wind turbines in each cluster.[30]

It should also be noted that other sources of energy, and in particular fossil fuels, are responsible for considerable visual impacts, with little suggestion this infrastructure is considered aesthetically pleasing by even a minority.

4.4 Social impacts

As noted above, the indirect health effects accompanying wind power are likely to be closely tied to the attitudes of individuals towards wind farms. This in turn can be affected by the way in which development is managed, and perceptions regarding the impact that wind developments might have on health and housing prices. Levels of support for wind vary considerably, and there is a lack of academic data in Australia[30], however there have been some large-scale surveys.

4.4.1 Community attitudes

It is difficult to get a realistic picture of the levels of support for wind farms, with a noticeable gap “between the stated high levels of support for wind farm development and the actual lower success rate and documented opposition to wind farm development proposals”.[30] While some local governments have argued that wind farms can “ignite significant, long-running social conflict and division within rural communities”, others note that perceived levels of opposition are often the result of a vocal minority seeking media exposure and political attention.[30]

Despite these inconsistencies, there is strong evidence that wind farms are on the whole viewed positively. There is broad support for the construction of more wind farms in Australia demonstrated by several surveys that have been carried out over the past 10 years. 95 per cent of respondents in a Victorian survey from Auspoll and a national survey from the Australian Research Group (2003) supported wind farms.[56,58] A 2006 CSIRO survey reported 65 per cent of all participants agreed with the growth of large-scale wind farms in Australia[30], while a 2010 survey of over 200 people and 300 businesses in NSW found 85 per cent supported wind farms in NSW, with 60 per cent supporting them at 1-2 kms from their residence.[30]

This pattern of support seems to be repeated internationally, with about 70 per cent of EU citizens expressing strong support for wind farms through the 'Eurobarmoeter' (with only 5 per cent opposition)[59]; 70 per cent of respondents expressing some level of support for a wind farm in Franklin, NZ (although this was reduced if the farm was to be "an obvious feature from their properties")[54]; a survey from the UK showing approximately 75 per cent of local residents supported their wind farm[54]; and a poll in Germany finding that 75-85 per cent of respondents agreed with the claim "I approve of wind turbines in general".[60]

There are certain issues that influence levels of support—in particular democratic process, community involvement and perceived economic benefits. One study found "actual and perceived local costs and benefits of wind farms…[were] strongly influenced by the design, implementation, and community engagement processes".[30] The need for transparency and honesty is stressed elsewhere, with one report noting, for example, "an increase in community reaction can occur if an intruding noise, which was supposed to be inaudible or barely perceptible, is readily heard by the community".[33]

However, it also seems that attitudes such as "pre-existing concerns that rural communities are politically neglected by urban centres, commitment to an anti-development stance, and opposition to a 'green' or 'climate action' political agenda" play a negative role and are unlikely to be mitigated by changes to the developments themselves.[30] This underlines the perceived trade-off between global concerns and local costs that opponents often emphasise[61], resulting in those from local communities sometimes "feeling as though they are asked ... to subvert some morally significant values in favour of others".[30]

Other reports suggest first-hand experience of wind farms can increase support. For example, surveys undertaken in WA showed nearly two thirds of respondents in the area where a wind farm was constructed felt *more* in favour after its construction, with only 1.7 per cent being more opposed, and 87.5 per cent stating they would be in favour of the construction of another wind farm nearby.[61]

4.4.2 Community owned wind farms

Perhaps the most promising model of wind power in terms of community support is co-operatives where the community have a significant financial stake. Community owned wind farms are common in Denmark and Germany, and are gaining support in other countries including Australia. However there is more research required in the Australian context to ascertain the extent to which such projects enjoy greater support.

There are claims that community ownership generally increases support for wind projects[62], with high levels of support in Denmark and Germany also indicating such a connection.[59] The tendency for higher support with community involvement is also reinforced by findings that involvement in the planning and decision-making process, perceived fairness and transparency all impact on community acceptance. While one study found that perceived economic benefits had the largest impact on acceptance, over and above concerns about involvement[60], such benefits are more likely to accrue to the community in community owned operations.

Aside from increased support, such community owned projects can have several other benefits—for example, Hepburn Wind notes that some of its revenue is used for community projects, skills are provided to volunteers, and employment has been created through local sourcing of construction resources and purchasing local services.[63]

Not all community or cooperative-run wind farms are successful, however. One literature review indicated that the success of such projects depends on several factors, including the degree of cohesiveness already evident in the community and the genuine engagement with the community.[64] Despite these caveats, most available literature suggests that such operations have the potential to mitigate opposition to wind farms, and provide greater local benefits.

4.4.3 Economic consequences

Wind farms are associated with both economic benefits—through increased jobs and incomes for home-owners—as well as costs such as decreased house prices.

It is beyond the scope of this report to fully consider the economic consequences of wind farm developments, however perception of economic consequences can bear on the level of support for wind farms and indirect effects such as annoyance, and these will be considered here.

Wind energy creates considerable amounts of jobs, especially during construction. It has been claimed that projected investments in the renewable energy industry will see this sector become a bigger employer than fossil fuels worldwide.[65] Land-owners also receive income from hosting wind turbines, although this can be the cause of conflict where neighbouring properties do not support the turbines. The fear of decreasing property prices is one reason given for opposition to wind farms, although several studies suggest that property prices are not affected. [30]

Wind farms may also have an affect on tourism, which can be both positive and negative. While they can attract tourists and boost the local economy, their impact on the scenery may be detrimental to tourism in some cases.[30]

4.5 Land

Although there is some disagreement about the amount of land required in relation to energy output, it is clear that wind farms require large amounts of land. This has potential immediate impacts to do with resource conflict as well as more long-term possible consequences including impacts on biodiversity.

4.5.1 Land use

There are conflicting reports regarding the land-use efficiency of wind, with one report noting that “[w]ind farms produce less energy per m2 than other sources, such as large scale solar—current estimates are 2 W/m2”, which translates to approximately 4000m2/person if it were the sole supplier of Australia’s energy needs.[66] This compares to approximately 5-20 W/m2 for solar PV panels and 15 W/m2 for concentrating solar thermal. Even lower average estimates of .5 to 1 W/m2 have been suggested, due in part to the effect of ‘wind shadows’—changes to wind speed produced by turbines themselves that limit the energy that can be produced from large developments.[67]

Apart from direct land-use, the construction of wind farms can cause soil erosion[30], although this is not as great a problem as other energy sources such as coal and unconventional gas.

Unlike fossil fuels, wind is on the whole is also compatible with grazing and crops, and there even appear to be some benefits for livestock—for example, they often use the turbines for shade.[68] Wind energy also does not use the vast quantities of water that is required by fossil fuels, and installing wind turbines does not necessarily require substantial infringement on the eco-system, leading to a low overall environmental impact.

4.6 Biodiversity

One of the main issues raised with wind farms is their potential to affect avian life. Birds and bats can be damaged or killed by flying into turbines, as well as being negatively effected by habitat loss or disturbance. For off-shore wind-farms, there are also concerns about aquatic life, however these will not be considered in detail here as there are currently no proposals for off-shore wind-farms in Australia.

4.6.1 Avian mortality

The greatest hazard to the ecosystem from wind farms in Australia comes from their impact on birds and bats, which can die or be injured by flying into turbines—although it is important to note that this is at a rate far less than other sources of injury, and bird species are likely to benefit overall from reduced climate change.

The most comprehensive study identified was a cumulative risk model for four threatened or endangered species of birds—the orange-bellied parrot, Tasmanian Wedge-tailed Eagle, Swift Parrot and White-bellied Sea-eagle.[69] This study used both data and 'well-informed scenarios' from a wide range of individual wind-farm operations in Australia, taking into account a number of variations (such as the height at which birds fly; migratory cycles that cross multiple wind farms; the size, speed and visibility of the turbines; and avoidance behaviours). This suggested that overall death rates would be lower than often predicted in models that did not take these variables into account, though noted the lack of data in this area.

Another study considered the effects of offshore wind farms in the Nederlands and Denmark (Lindeboom et al).[70] These results were mixed, with some species avoiding the wind farm while others were indifferent or attracted. Migrating landbirds tended to show avoidance, altering their flight paths when it took them through the wind farms.

Despite a lack of concrete figures from all Australian wind farms, it has been estimated that the average death rate is 1-2 birds per turbine per year. One study conducted in Northern Tasmania found that the installation and operation of turbines did not significantly effect birdlife in the area, apart from avoiding the areas immediately around the turbines.[71] In a period of 8 months, 4 birds and 6 bats were recorded as killed in one area, with 3 bird and 3 bat deaths in the same period at another site. Overall bird death rates were reported as between 0.9 and 1.7 deaths per turbine per year. The birds were not endangered species, and it was noted that eagles in particular tended to exhibit avoidance behavior.[72]

Several studies point to the comparatively higher rate of avian mortality that results from collisions with automobiles, transmission towers and power lines, as well as the damage done by domestic and feral cats which is cause significantly more deaths.[30]

4.6.2 Other flora and fauna

There are few studies looking at the impact of wind farms on other species, however one report noted that: "Turbines are usually arrayed in the landscape with little change to pre-existing land use and thus local populations of fauna are generally not expected to alter from the levels at which they existed prior to construction of a wind farm."[69]

5. Comparisons with coal and gas

A discussion of the health and environmental impacts of solar and wind technology is only meaningful in a framework that considers the impacts of the energy generation technologies currently employed in Australia. At present, coal provides approximately 35 per cent of Australia's energy needs while gas is responsible for 23 per cent [74], with an expansion in the unconventional gas industry likely to see coal seam and shale gas occupy a greater role in the future. Given the wealth of evidence concerning the damaging impacts of coal, and to a lesser extent gas, it is clear that considerable health benefits will arise from replacing these technologies that need to be factored into the health profile of solar and wind.

This discussion is not intended to be an exhaustive survey of the literature on the impacts of coal and gas. In what follows, their direct and indirect impacts will be briefly considered in order to give a general context in which the health benefits of adopting large scale solar and wind technologies can be understood.

There are no primary studies that have been carried out on the heath impacts of coal in Australia[75], however the international evidence demonstrates the substantial impacts that the mining and burning of coal has on workers and the wider community. Each stage of coal processing produces pollutants, and there are significant occupational hazards attending its production.[76] The high level of GHG emissions from coal fired energy production adds a substantial health burden.

Conventional gas, while less damaging than coal in several respects, has far more direct and indirect health implications than renewable technologies. While there is a high degree of uncertainty regarding the impacts of unconventional gas, the available evidence suggests that there are potentially serious impacts through air, water, land and social pathways.[77]

5.1 Direct health impacts

Coal remains one of the most dangerous forms of energy generation from the perspective of workers[78], with up to 12 per cent of coal miners developing a potentially fatal disease such as pneumoconiosis, progressive massive fibrosis, emphysema, chronic bronchitis, or compromised lung function.[79] Although Australian operations are less dangerous than many, mine collapse, asphyxiation, explosion and diseases from coal dust still represent risks for workers.[76]

For the wider population, air pollution from coal combustion is the most serious threat to health. Coal combustion is responsible for the creation of damaging particulate matter (PM_{10} and $PM_{2.5}$), which is known to be associated with a wide range of negative health effects including respiratory problems (such as aggravation of asthma and decreased lung function), heart arrhythmia, higher rates of mortality from heart and lung disease, and allergic reactions among others.[73,75,80] Sulphur dioxide (SO_2) and nitrous oxide (NOx) emissions are also of concern, mainly for their contribution to the creation of PM.[79] A recent literature review also listed other toxic elements with serious health implications released with coal combustion, including arsenic, mercury, fluorine, cadmium, lead, selenium and zinc. These can accumulate in the environment, with the authors noting in particular that "[o]ver a third of all mercury emissions attributable to human activity come from coal-fired power stations".[76]

Gas produces substantially less PM than coal and Australian operations have relatively low air pollution impacts, however they are still responsible for non-negligible levels of pollutants such as NOx, which contributes to photochemical smog.[81] Information about the impact of unconventional gas operations on air quality in Australia is scarce and they are likely to be lower than their US counterparts, however there are potential impacts from fugitive emissions; emissions from equipment; evaporation from wastewater ponds, spills, well blowouts, venting and flaring.[77] Furthermore, it has been suggested that *any* level of such pollutants can have an impact at the population level.[10]

Wastewater is a potential hazard in both coal and unconventional gas operations. Coal mine discharge has been found to have severely compromised freshwater streams in NSW.[82] Both fracturing chemicals and naturally occurring contaminants represent real risks for water quality in unconventional gas operations[77], as illustrated by the recent contamination of an aquifer by naturally occurring uranium.[83]

The cumulative effect of pollutants from coal fired power generation is notable, with increases in mortality from lung cancer, heart, respiratory and kidney diseases in affected communities. One review of evidence found "[t]he risk of premature death for people living within 30 miles of coal-burning power plants…[has been] quoted to be three to four times that of people living at a distance".[76] In addition, adults living in coal mining communities have been found to be at greater risk of cardiopulmonary disease, chronic obstructive pulmonary disease, hypertension, and lower self-rated health and reduced quality of life generally.[75] There are also higher rates of birth defects and low birth weight in children and infants in coal mining communities.[75] Considering the combined costs to health from pollutants such as PM, SO_2 and NOx, a report on the externalities of energy generation in Australia found the total health damage costs of three of Australia's coal-fired power stations to be "equivalent to an aggregated national health burden of around $A2.6 billion per annum."[73]

The cumulative health effects of unconventional gas extraction are uncertain, however data from several sources demonstrates that such gas developments are responsible for emissions of a complex mixture of pollutants, surpassing those from vehicle traffic in some US regions.[84] One measurement of the health risks directly associated with air pollution due to unconventional gas developments in the US estimated cumulative cancer risks at "6 in a million for residents >1/2 from wells and 10 in a million for residents ≤1/2 mile from wells"[85], while another indicated adverse effects on infant health, identifying several potential health pathways.[86]

In addition to health effects from air and water pollution, coal operations are also connected to increased road traffic accidents and have been associated with increases in criminal and other anti-social behaviours.[75] Evidence indicates similar issues arising in gas operations, and in particular there are concerns over the use of fly-in/fly-out workers.[87]

5.2 Indirect health impacts

One of the most serious health impacts from fossil fuels is the release of greenhouse gases. Coal fired power plants produce around 1000 kg of CO2e per megawatt hour[79,81,88]—the highest level of GHG emissions per unit energy of any form of energy generation. A WHO study estimated that "global warming that has occurred since the 1970s caused over 140 000 excess deaths annually by the year 2004" [89], primarily through the impact of malnutrition, diarrhoea, malaria, floods, and cardiovascular disease in developing countries. While it is impossible to precisely calculate the causal effect of coal power on health through its influence on climate change, it is clear that Australia's reliance on coal for use domestically and for export burdens us with a considerable moral responsibility.

While conventional gas fares somewhat better in respect to GHG release, with many reports estimating its combustion is responsible for approximately half (or less) the CO2e emissions of coal[90], this remains a substantial amount in absolute terms. Furthermore, debate over the GHG impact of fugitive methane emissions renders such figures uncertain at best for unconventional gas, with some estimates suggesting it offers no GHG advantages over coal.[91,92] The GHG emissions from solar and wind technologies are by comparison negligible, and mostly arise from the non-renewable energy technologies used in their production.[73]

Coal and gas production is also responsible for considerable environmental damage through water, air and land pathways. For coal, this includes damage through acidification affecting land and water (especially from sulphurous black coal), eutrophication (responses by the water system to additional substances, such as algal blooms or reduced oxygen content) and waste such as ash.[41] The production of coal fired energy also requires substantial water use, with the five coal plants in the Latrobe Valley using 125 billion litres annually—approximately 13-17GL a year per 1000 MW plant, or the equivalent of about one third of Melbourne's water supply.[54] This creates resource competition that is likely to be further exacerbated by climate change.

The environmental impact of unconventional gas in Australia is uncertain, however some degradation of land and water is likely, and a potential for serious negative impacts on biodiversity and ecosystem health.[37]

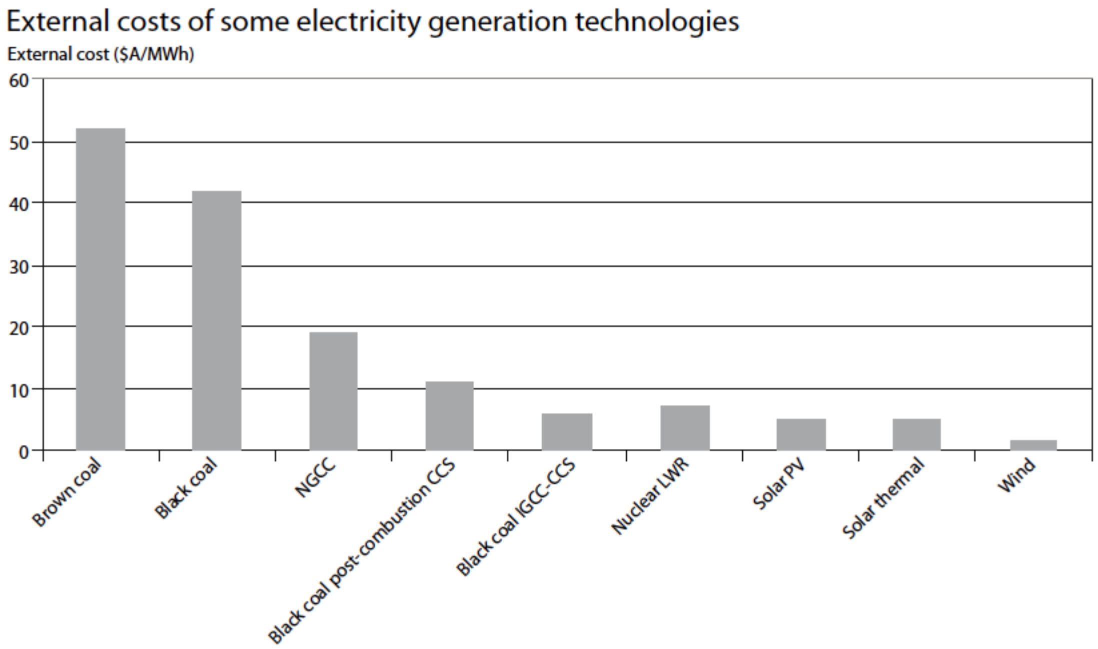
5.3 Comparative profile

It is obvious that the technologies currently providing the majority of Australia's energy needs place a considerable burden on human health. A review of the international evidence for coal's effects found that there "are clear indications …that there are serious health and social harms associated with coal mining and coal-fired power stations for people living in surrounding communities".[75] While conventional gas is somewhat less impactful, its negative effects are also substantially higher than any renewable energy alternative. The impacts of extracting coal seam and shale gas using fracturing is beset with uncertainty, however there are several serious concerns.

Comparing the externalities generated by coal, gas and renewable energy, the Australian Academy of Technological Sciences and Engineering estimated costs of "$A19/MWh for natural gas, $A42/MWh for black coal and $A52/MWh for brown coal" compared to "$A5/MWh for solar photovoltaic electricity and $A1.50/MWh for wind power" (Figure 5 below).[73] There is some question of whether these figures adequately capture the impact of wind farms, however. The authors note that "there is little information on which to base the value of loss of visual amenity"[73] (although this criticism will also affect other forms of energy generation). The cost of noise was linked to information on 'willingness to pay' found in studies on traffic noise, however as noted previously it is possible that wind turbine noise is more annoying, so this might not adequately reflect the costs.

However, even if the estimated externalities of visual impacts and noise have been substantially underestimated, this would still leave wind with considerably lower external costs than other energy generation technologies. These figures are indicative of the substantial health benefits that would attend the replacement of coal and gas with the adoption of large-scale solar and wind technologies.

Figure 5: External costs associated with energy generation technologies in Australia. Source: ATSE



6. Conclusion

Wind energy has, for the most part, a high degree of support in Australia. The considerable benefits it represents in terms of the reduction of GHG emissions, coupled with Australia's excellent wind resources, make it a natural choice to play a considerable role in our energy future.

However, apart from the obstacles arising from technological limitations and the variable nature of wind, there has also been considerable public opposition to the expansion of the industry. Opponents most often cite the visual intrusion that wind turbines are argued to represent, together with fears associated with the health implications of audible and sub-audible noise.

More than any other energy source, the health implications of exposures to wind farms seem to be largely indirect. This is especially the case for the levels of noise that accompany Australian wind farms, which are subject to tight planning regulations that restrict noise exposures to levels below those associated with nearly all possible health implications. Although noise from turbines has been associated with reports of annoyance and sleep disturbance in numerous studies, it is clear that attitudes towards wind farms and other subjective factors play a central role in determining the extent to which such effects are felt. While the effect that annoyance and sleep disturbance can have on quality of life cannot be dismissed, however these impacts need to be weighed against the benefits of wind technology and compared to the health impacts of other forms of energy generation.

The indirect, subjective nature of such effects has implications for how they are treated. In particular, it suggests that the way developments are managed is important, and also indicates the damage that can be done by those seeking to exploit fears about 'wind turbine syndrome' and 'vibroacoustic disease' for which there is no evidence. Although there is some suggestion that the character of LFN makes it more annoying than other noise at the same level, and some minor uncertainty about its effects, the studies purporting to demonstrate these syndromes is deeply flawed and likely to be responsible for fomenting anxieties which can have very real health effects.

The other major impact of wind energy of concern in Australia is its impact on the bird and bat population. Wind farms are responsible for somewhere in the vicinity of 40,000 bird deaths per annum, some of which are threatened species. However, this is minor when compared to deaths attributable to cats, cars, power lines and other causes, and the predicted impact of climate change.

The character of impacts from wind turbines is such that large global and national gains can come at the price of some minor reduction in the quality of life for those living in close proximity to wind farms, however models such as community ownership seem to lessen such impacts. On balance the potential gains far exceed these costs, especially once wind is examined in comparison to the far more damaging effects of fossil fuels, and there are some straightforward means by which the more serious of these can be mitigated through thoughtful planning and improved communication and technology.

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