Chapter 9

Wind Energy

9.1 Summary

KEY MESSAGES

- Wind resources are a substantial source of low to zero-emission renewable energy, with a proven technology. Wind farms with installed capacities of more 100 megawatts (MW) are now common.
- Australia has some of the world's best wind resources along its south-western, southern and south-eastern margins. More isolated areas of the eastern margin also have excellent wind resources.
- Wind energy is the fastest growing renewable energy source for electricity generation, although its current share of total primary energy consumption is only 0.2 per cent in Australia.
- Further rapid growth in wind energy in Australia will be encouraged by government policies, notably the Renewable Energy Target (RET) and emissions reduction targets, increased demand for low emission renewable energy and lower manufacturing costs.
- In Australia, the share of wind energy in total electricity generation is projected to increase from 1.5 per cent in 2007–08 to 12.1 per cent in 2029–30.
- Extension and other augmentation of the electricity transmission network may be required to access dispersed (remote) wind energy resources and to integrate the projected increase in wind energy electricity generation.

9.1.1 World wind energy resources and market

- The world's wind energy resource is estimated to be around one million gigawatts (GW) for total land coverage. The windiest areas are typically coastal regions of continents at mid to high latitudes, and mountainous regions.
- Wind electricity generation is the fastest growing energy source, increasing at an average annual rate of nearly 30 per cent between 2000 and 2008. The major wind energy producers are Germany, the United States, Spain, India and China.
- The world outlook for electricity generation from wind energy will be strongly influenced by government climate change policies and the demand for low-emission renewable energy at affordable prices.
- The IEA projects the share of wind energy in total electricity generation will increase markedly from 0.9 per cent in 2007 to 4.5 per cent in 2030 – from 1.4 per cent to 8.1 per cent in OECD countries and from 0.3 per cent to 2.2 per cent in non-OECD countries.

9.1.2 Australia's wind energy resources

- Australia has some of the best wind resources in the world, primarily located in western, south-western, southern and south-eastern coastal regions but extending hundreds of kilometres inland and including highland areas in south-eastern Australia (figure 9.1). There are large areas with average wind speeds suitable for high yield electricity generation.
- Local topography and other variability in the local terrain such as surface roughness exert a major influence on wind speed and wind variability. This necessitates detailed local investigation of potential sites for wind farms.

9.1.3 Key factors in utilising Australia's wind energy resources

- Government policies, particularly carbon emissions reduction targets and the Renewable Energy Target (RET), are expected to underpin the future growth of Australia's wind energy industry. The operation of wind turbines produces no greenhouse gas emissions, and emissions involved in the development stage are low compared with electricity generation from other sources.
- Wind energy is a proven and mature technology with low operating costs. Both the size of turbines and wind farms have increased, with farms of more than 100 MW combined capacity now common and substantially larger wind farms proposed.

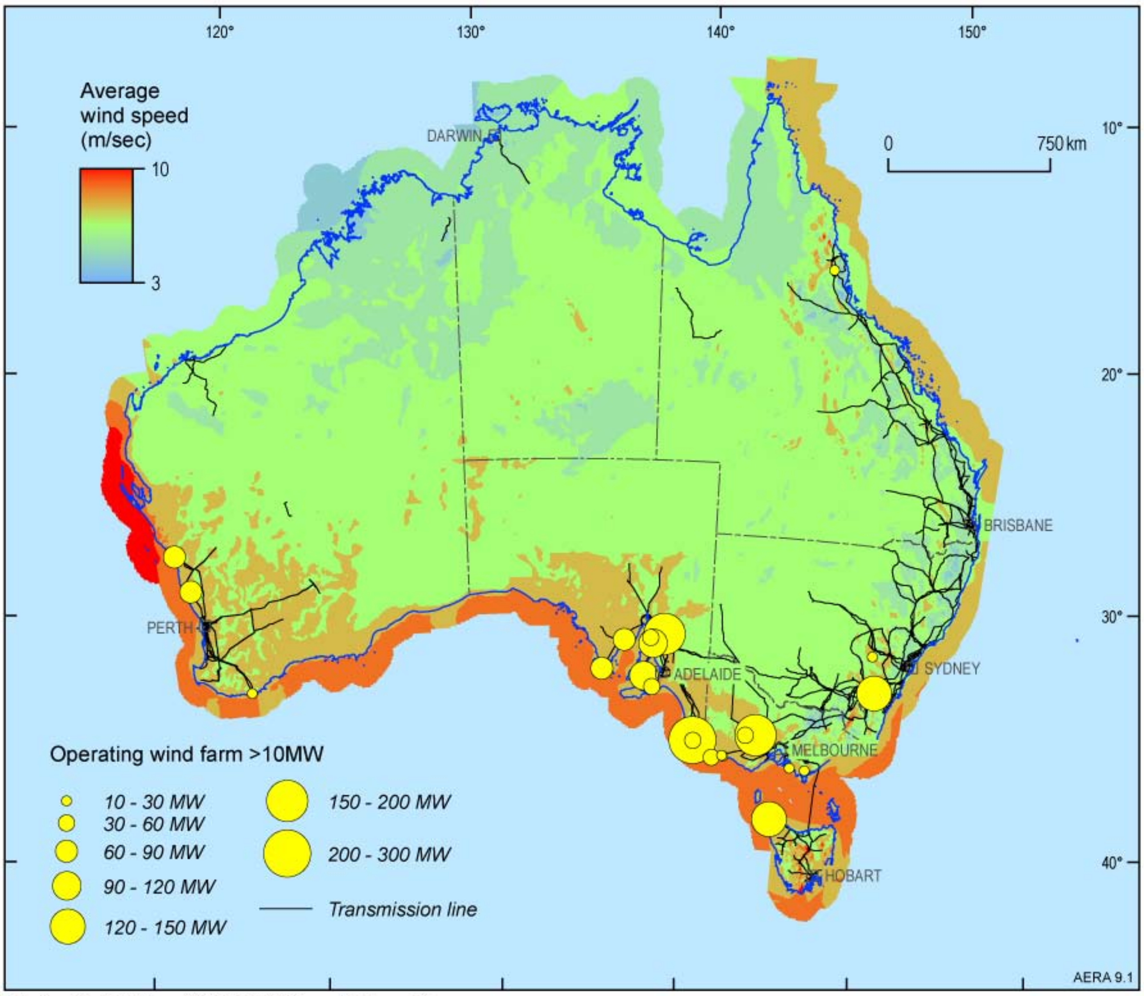

Figure 9.1 Australia's wind resources

Source: Windlab Systems Pty Ltd, DEWHA Renewable Energy Atlas (wind map data); Geoscience Australia

- Grid constraints – lack of capacity or availability – may limit further growth of wind energy in some areas with good wind resources, particularly in South Australia. In such areas, upgrades and extensions to the current grid may be needed to accommodate significant further wind energy development. Elsewhere, current grid infrastructure should be adequate for the levels of wind energy penetration projected for 2030.
- Variability imposes an upper limit on wind energy penetration, however this is not likely to be reached at the level of wind energy projected to 2030. This limit can be extended by better wind forecasting (allowing the grid to react to projected changes in wind conditions), demand side management (shedding or adding load to match wind conditions) and even the addition of storage nodes to the grid (moving excess wind energy to higher demand periods).
- Wind turbine manufacturing output is doubling every three years. There is also a shift from European and United States' production to lower cost manufacturing centres in India and China. Both of these trends will result in a reduction in turbine costs.
- Access to Australia's onshore wind resources is likely to be sufficient to meet industry development requirements over the outlook period. There are currently no plans to develop higher cost offshore wind resources.

9.1.4 Australia's wind energy market

- In 2007–08, Australia's wind energy use represented only 0.2 per cent of total primary energy consumption and 1.5 per cent of total electricity generation. However, wind energy is the fastest growing energy source in Australia with an average annual growth of 69.5 per cent since 1999–00.
- In October 2009, there were 85 wind farms in Australia with a combined installed capacity of 1.7 GW. These power stations are mainly located in South Australia (48 per cent), Victoria (23 per

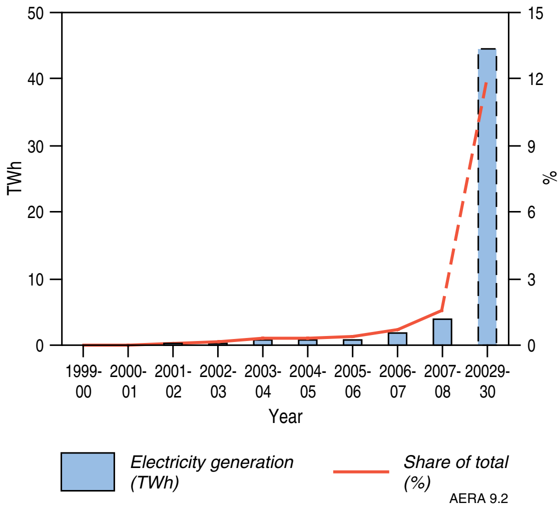

Figure 9.2 Australia's wind energy market to 2029–30

Source: ABARE 2010

cent) and Western Australia (12 per cent). A further 11.3 GW of wind energy capacity has been proposed for development in Australia.

- In the latest ABARE long-term energy projections that include a 5 per cent emissions reduction target, wind electricity generation in Australia is projected to increase sharply from 4 TWh in 2007–08 to 44 TWh in 2029–30 (figure 9.2). The share of wind energy in total electricity generation is projected to increase from 1.5 per cent in 2007–08 to 12.1 per cent in 2029–30.

9.2 Background information and world market

9.2.1 Definitions

Wind is a vast potential source of renewable energy. Winds are generated by complex mechanisms involving the rotation of the Earth, the heat capacity of the Sun, the cooling effect of the oceans and polar ice caps, temperature gradients between land and sea, and the physical effects of mountains and other obstacles.

Wind energy is generated by converting wind currents into other forms of energy using wind turbines (figure 9.3). Turbines extract energy from the passing air by converting kinetic energy from rotational movement via a rotor. The effectiveness of this conversion at any given site is commonly measured by its energy density or, alternatively, as a capacity factor (box 9.1). Wind energy is primarily used for electricity generation, both onsite and for transport to the grid. Wind energy is also used to pump bore water, particularly in rural areas.

9.2.2 Wind energy supply chain

The wind energy supply chain is relatively simple (figure 9.4). In the energy market, wind resources are utilised for electricity generation, either linked to the grid or for off-grid applications in remote areas. Wind

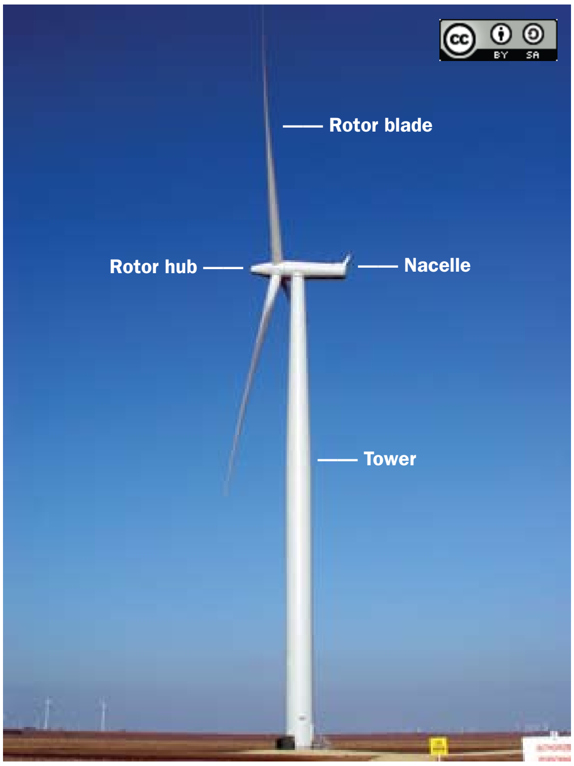

Figure 9.3 A modern wind turbine

Source: Wikimedia Commons

BOX 9.1 CAPACITY FACTOR

Estimates of electricity generation are generally calculated by modelling the interaction between the wind distribution and a particular turbine. The ratio of actual yield to the maximum output of the machine is commonly referred to as a capacity factor. Each type of turbine has a different capacity factor for any given site.

For example, a wind turbine with a 1 MW capacity and 30 per cent capacity factor will not produce its theoretical maximum annual production of 8760 MWh (1MW * 24 hours * 365 days). Rather it is expected to produce 2628 MWh (1MW * 24 hours * 365 days * 0.3 capacity factor).

The capacity factor should not be confused with 'efficiency' which is a measure comparing the actual output with the energy contained in the passing wind. Wind turbines are limited by physical factors to an efficiency of about 60 per cent (Betz's Law). The best wind turbines are presently around 44 per cent efficient.

resources are also used to pump water, especially in rural Australia.

Modern wind energy prospecting typically uses three levels of wind resource mapping:

1. regional-scale 'mesoscale' wind speed maps, to identify favourable regions. These maps are

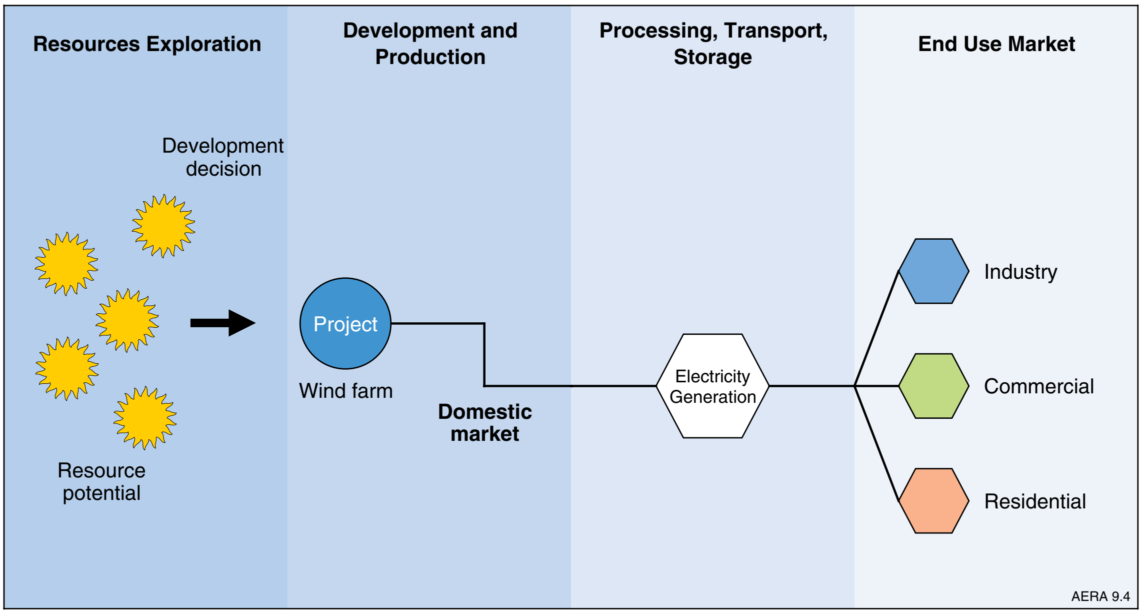

Figure 9.4 Australia's wind energy supply chain

Source: ABARE and Geoscience Australia

compiled using wind measurements from balloons combined with atmospheric models;

2. farm level 'microscale' wind resource mapping to account for local variations in wind speed; and
3. micro-siting studies to determine optimal locations for siting of individual turbines. This mapping requires input from long term sensors installed on the site.

Final siting of wind farms depends on both technical and commercial factors, including wind speed and topography, as well as proximity to transmission lines, access to land, transport access, local development zoning and development guidelines, and proximity to markets.

In the electricity market, wind energy is automatically dispatched, meaning that the wind electricity must be consumed before other, more controllable, sources are dispatched. Since March 2009 new wind generators greater than 30 MW must be classified as 'semi-scheduled' and participate in the central despatch process (AER 2009).

Electricity produced from the individual turbines is stepped up by means of a transformer and high voltage switch and collected in the central switchyard of the wind farm. It is then fed to the electricity transmission grid substation with further transformers and switchgear. The electricity is distributed to the industrial, commercial and residential markets in the same manner as electricity generated from any other source.

Small wind turbines (typically less than 10 kW) are commonly used in remote locations isolated from the grid for a variety of industrial, commercial and household needs, usually in conjunction with some form of storage.

9.2.3 World wind energy market

The wind energy industry is the fastest growing renewable energy source in many countries and is expected to continue to grow rapidly over the period to 2030. Production of wind energy is largely concentrated in Europe and the United States. However, there has also been rapid growth in the wind energy industries in China and India.

Resources

The world's wind energy resource is estimated to be about one million GW for total land coverage. Assuming only 1 per cent of the area is utilised and allowance is made for the lower load factors of wind plant, the wind energy potential would correspond to around the world total electricity generation capacity (WEC 2007).

The windiest areas are typically coastal regions of continents at mid-to high latitudes and in mountainous regions. Locations with the highest wind energy potential include the westerly wind belts between latitudes 35° and 50°. This includes the coastal regions of western and southern Australia, New Zealand, southern South America, and South Africa in the southern hemisphere, and northern and western Europe, and the north eastern and western coasts of Canada and the United States. These regions are generally characterised by high, relatively constant wind conditions, with average wind speeds in excess of 6 metres per second (m/s) and, in places, more than 9 m/s.

Regions with high wind energy potential are characterised by:

Table 9.1 Key wind energy statistics, 2008

	unit	Australia 2007–08	OECD 2008	World 2008[a]
Primary energy consumption[b]	PJ	14.2	660.2	767.8
Share of total	%	0.2	0.3	0.1[c]
Average annual growth, 2000–2008	%	69.5	26.2	27.7
Electricity generation				
Electricity output	TWh	3.9	183.4	213.3
Share of total	%	1.5	1.7	0.9[c]
Electricity capacity	GW	1.3	104.3	120.8

a ABARE estimate **b** Energy production and primary energy consumption are identical **c** 2007 data
Source: ABARE 2009a; IEA 2009a; GWEC 2009a

- high average wind speeds;
- winds that are either constant or coinciding with peak energy consumption periods (during the day or evening);
- proximity to a major energy consumption region (i.e. urban/industrial areas); and
- smooth landscape, which increases wind speeds, and reduces the mechanical stress on wind turbine components that results from variable and turbulent wind conditions associated with rough landscape.

Because of wind variability, the energy density at a potential site – commonly described as its **capacity factor** (box 9.1) – is generally in the range of 20–40 per cent. While the majority of areas in locations convenient for electricity transfer to the grid are located onshore, offshore sites have also been identified as having significant potential for wind energy, both to take advantage of increased wind speeds and to increase the number of available sites. Offshore locations also help reduce turbulence and hence stress on machine components. There have been wind turbines deployed in shallow seas off northern Europe for more than a decade. Offshore sites are expected to make an increasingly significant contribution to electricity generation in some countries, notably in Europe, where there are increasing difficulties in gaining access to onshore sites.

Primary energy consumption

In the wind energy market, energy production, primary energy consumption and fuel inputs to electricity generation are the same as there is essentially no international trade and no ability to hold stocks of wind energy. Wind energy has increased from a 0.03 per cent share of global primary energy consumption in 2000 to around 0.1 per cent in 2007 (IEA 2009a).

Electricity generation

Wind energy accounted for 0.9 per cent of world electricity generation in 2007 and 1.7 per cent of OECD electricity generation in 2008. Global wind electricity generation has increased strongly, from 31 terawatt-hours (TWh) in 2000 to 213 TWh in 2008, representing an average annual growth rate of nearly 28 per cent (table 9.1).

Wind energy use is growing rapidly in the industrialised world: capacity has been doubling about every three and half years since the early 1990s. The reasons for this rapid growth are environmental; it is a renewable and low emission source of energy. Because of the simplicity of its technology and resource abundance, it has emerged as one of the leading renewable energy industries, well aligned with governments' search for commercially-viable renewable energy sources. There is also increasing interest in the developing world because it can be readily installed to meet local electricity needs.

The wind energy market is dominated by two regions: Europe and North America (figure 9.5). In 2007, 61 per cent of the world's wind electricity generation was

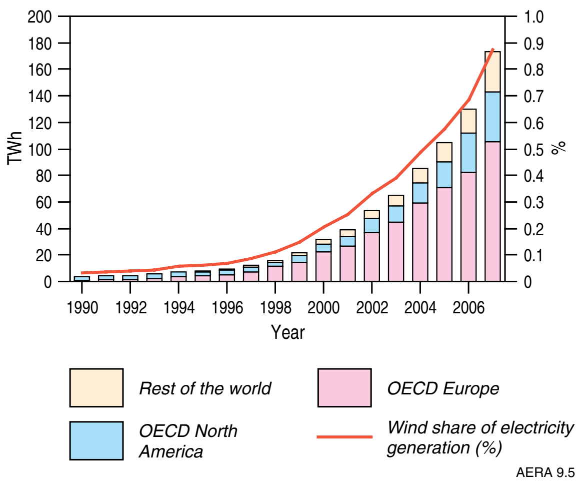

Figure 9.5 World wind electricity generation, by region
Source: IEA 2009a

in OECD Europe and 22 per cent was in OECD North America, mainly in the United States.

The main wind energy producers in Europe are Germany (23 per cent of world wind electricity generation in 2007), Spain (16 per cent) and Denmark (4 per cent) (figure 9.6a). While growth in wind electricity generation in these countries has slowed in recent years, other major producers have emerged, including the United Kingdom, France and Italy. The strong presence of the wind energy industry in the European Union, where it is the fastest growing energy source, is largely the result of government initiatives to have renewable energy sources provide 21 per cent of electricity generation by 2010 (Commission of the European Communities 2005).

The United States produced 35 TWh of wind energy in 2007, accounting for 20 per cent of world wind energy production. Currently, the strongest legislative support for the wind energy industry is a 2.1 cents per kWh tax credit allowed for the production of electricity from utility scale wind turbines (the Wind Energy Production Tax Credit). In addition, renewable portfolio standard (RPS) policies with targets for a renewable share of electricity generation have been implemented in 28 US states. A proposed national RPS, which would be similar to Australia's Renewable Energy Target, is before the United States Congress.

In Asia, India (with 7 per cent of world wind electricity generation in 2007) and China (5 per cent) have emerged as significant wind energy producers. India has supported the development of the wind energy industry through research and development support, demonstration projects and policy support. China's National Energy Bureau identified wind energy as a priority for diversifying China's energy mix away from coal. Both countries are now manufacturers and exporters of wind turbines.

Wind energy contributes a significant proportion of electricity in some countries, particularly Denmark (19 per cent in 2007), Portugal (13 per cent), Spain (10 per cent) and Germany (6 per cent) (figure 9.6b).

Australia is the fourteenth largest wind producer in the world (figure 9.6a). However, wind energy accounted for only 1.5 per cent of Australia's total electricity generation in 2007–08 (table 9.1).

Installed electricity generation capacity

Global installed wind energy capacity has risen sharply from 6.1 GW in 1996 to 121.5 GW in 2008 (table 9.2). In 2008, 27 GW of new capacity was installed, an annual increase of 29 per cent, with more than half of the new capacity developed in the United States and China.

At the end of 2008 the United States had the highest installed capacity (25 GW) followed by Germany (24 GW), Spain (17 GW), China (12 GW)

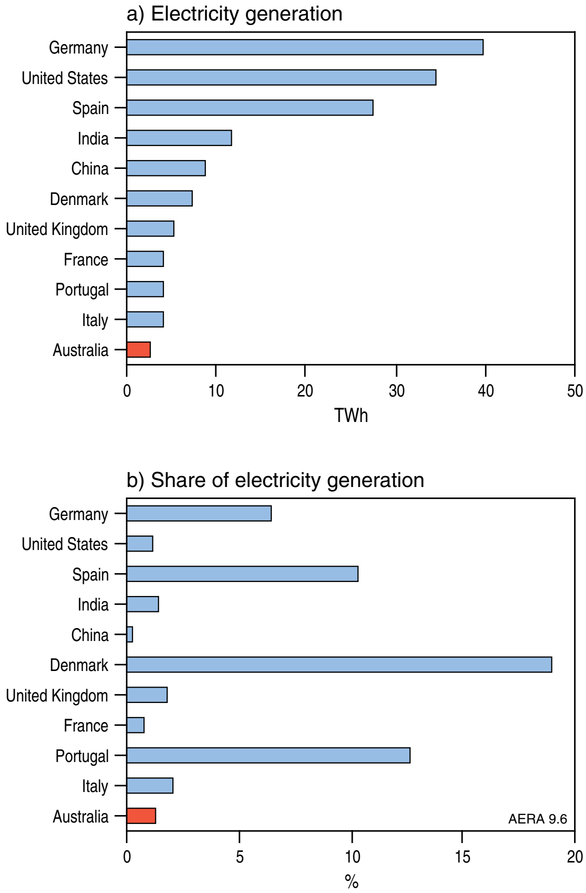

Figure 9.6 Wind electricity generation, major countries, 2007

Source: IEA 2009a

Table 9.2 Installed capacity in major wind electricity generating countries, 2008

Country	Installed capacity GW	Share of world %
1. United States	25.2	21
2. Germany	23.9	20
3. Spain	16.8	14
4. China	12.2	10
5. India	9.6	8
6. Italy	3.7	3
7. France	3.4	3
8. United Kingdom	3.2	3
9. Denmark	3.2	3
10. Portugal	2.9	2
14. Australia	1.3	1
World	121.5	100

Source: GWEC 2009

and India (10 GW). Together these five countries accounted for more than 72 per cent of global installed capacity. The fastest growing region since 2006 has been Asia, accounting for nearly one third of newly installed wind capacity in 2008 (but only 12 per cent of production in 2007).

World wind energy market outlook

Government policies will be a major contributing factor to the future development of the industry. Renewable energy targets, for example, provide economic incentives to invest in least cost sources of renewable energy resources. Wind energy is likely to become more important in the fuel mix, because wind energy technologies have been demonstrated to be commercially viable and there is still significant development potential for wind resources.

The rapid improvement in wind turbine efficiency and grid integration technology over the past decade is expected to continue, adding to the overall efficiency of the industry. Reducing the cost of wind energy generation, through lower manufacturing costs and economic gains from larger operations, may also enhance the competitiveness of the industry.

According to the IEA (2009b), the global wind energy industry is projected to continue to grow strongly throughout the period to 2030, increasing its share of electricity generation in many countries. In the IEA reference case projections, world electricity generation from wind energy is projected to increase at an average annual rate of 9.9 per cent between 2007 and 2030 (table 9.3). As a result, the share of wind energy in total electricity generation is projected to increase sharply from 0.9 per cent in 2007 to 4.5 per cent in 2030.

OECD countries are expected to continue to be the main wind energy producers over the outlook period. In the OECD region, the share of wind energy in total electricity generation is projected to rise from 1.4 per cent in 2007 to 8.1 per cent in 2030. Wind energy use is also projected to rise strongly in non-OECD countries – by 2030, non-OECD countries are projected to account for 30 per cent of world wind electricity generation (figure 9.7).

In the IEA's 450 ppm climate change policy scenario (stabilising the concentration of atmospheric greenhouse gases at 450 parts per million), the economic incentives to invest in clean renewable energy sources are considerably greater than those of the reference case. As a result, the share of wind energy in world electricity generation is projected to increase to 9.3 per cent in 2030 (more than double the share in the reference case). In the OECD region, the wind energy share is projected to increase to 12.8 per cent in 2030 under this scenario.

Table 9.3 IEA reference case projections for world electricity generation from wind energy

	unit	2007	2030
OECD	TWh	150	1068
Share of total	%	1.4	8.1
Average annual growth, 2007–2030	%	-	8.9
Non-OECD	TWh	24	468
Share of total	%	0.3	2.2
Average annual growth, 2007–2030	%	-	13.8
World	TWh	173	1535
Share of total	%	0.9	4.5
Average annual growth, 2007–2030	%	-	9.9

Source: IEA 2009b

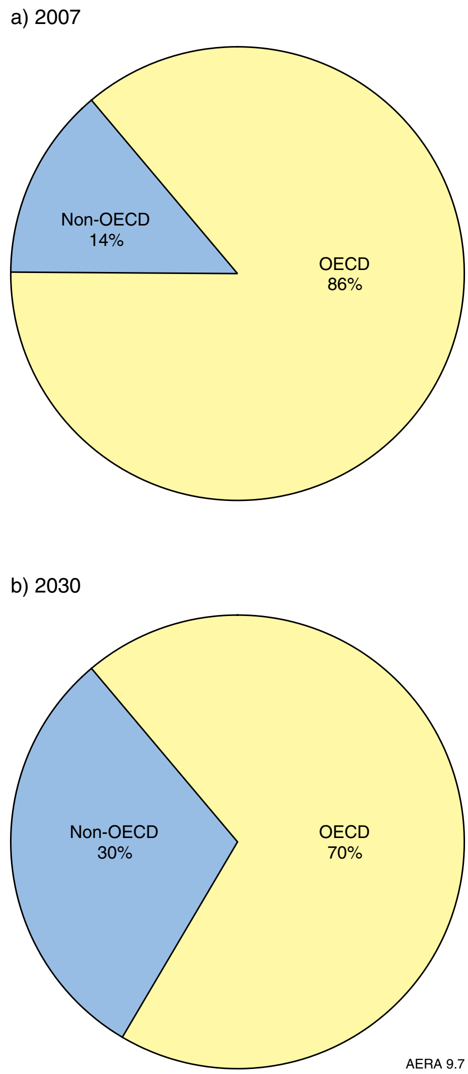

Figure 9.7 IEA reference case projections for wind energy in the OECD and non-OECD regions, 2007 and 2030

Source: IEA 2009b

9.3 Australia's wind energy resources and market

9.3.1 Wind energy resources

Australia has some of the best wind resources in the world. Australia's wind energy resources are located mainly in the southern parts of the continent (which lie in the path of the westerly wind flow known as the 'roaring 40s') and reach a maximum around Bass Strait (figure 9.8). The largest wind resource is generated by the passage of low pressure and associated frontal systems whose northerly extent and influence depends on the size of the frontal system. Winds in northern Australia are predominantly generated by the monsoon and trade wind systems. Large-scale topography such as the Great Dividing Range in eastern Australia exert significant steering effects on the winds, channelling them through major valleys or deflecting or blocking them from other areas (Coppin et al. 2003). Deflection of weaker fronts from frontal refraction around the ranges of the Divide in south eastern Australia creates winds with a southerly component ('southerly busters') along the east coast.

In addition to the refractions by topography and heat lows over northern Australia, other major factors influencing wind resources are seasonal and diurnal variation in wind speed. Winds are strongest in winter and spring in western and southern Australia but the monthly behaviour differs from region to region. Variations in average monthly wind speed of up to 15–20 per cent over the long term annual average are not uncommon. There may be similar daily variations at individual locations, with increased wind speeds in the afternoon (Coppin et al. 2003).

Meso-scale maps show that Australia's greatest wind potential lies in the coastal regions of western, south-western, southern and south-eastern Australia (areas shown in orange to red colours in figure 9.8 where average wind speeds typically exceed 6.5 m/s). Coastal regions with high wind resources (wind speeds above 7.5 m/s) include the west coast south of Shark Bay to Cape Leeuwin, along the Great Australian Bight and the Eyre Peninsula in South Australia, to western Victoria and the west coast of Tasmania (figure 9.8). Good wind resources extend hundreds of kilometres inland and many of Australia's wind farms (current and planned) are located some distance from the coast. Inland regions

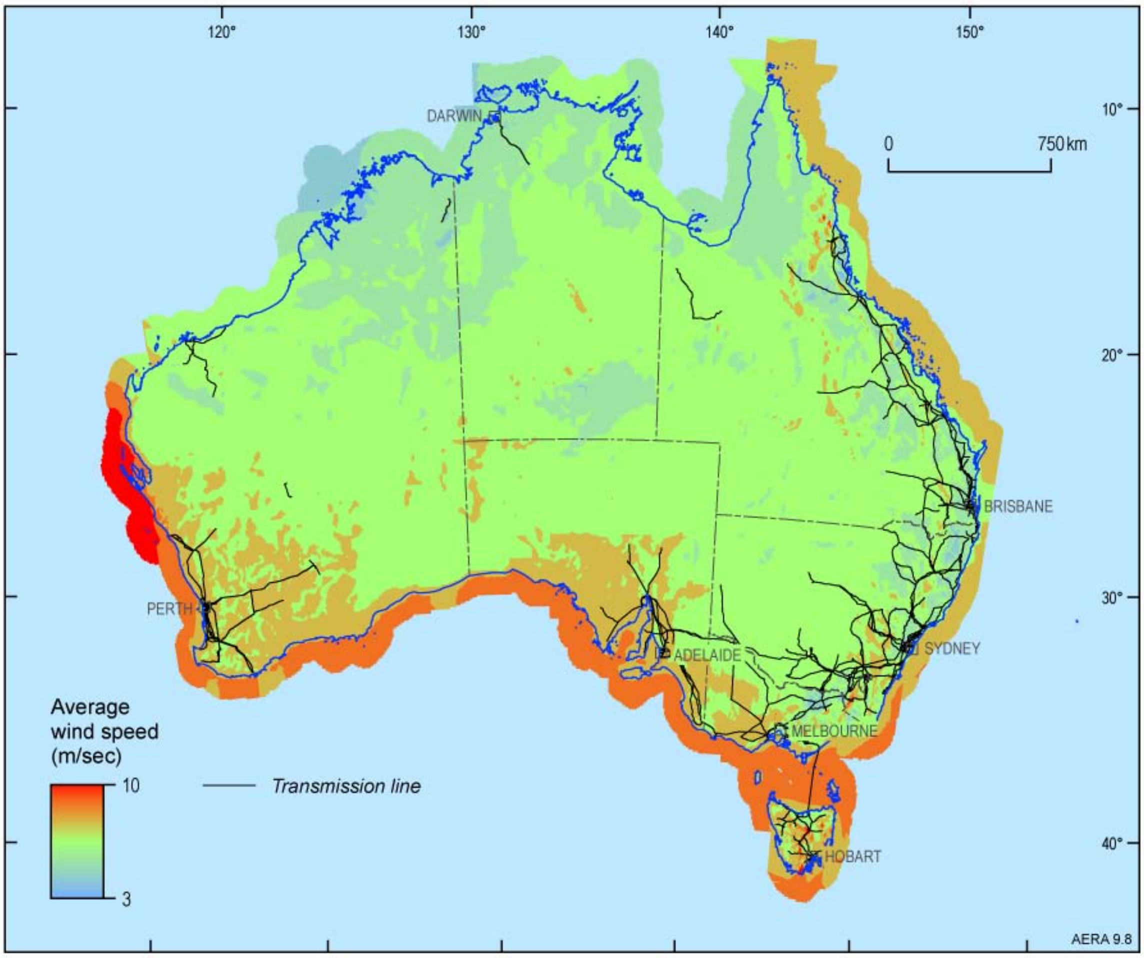

Figure 9.8 Predicted average wind speed at a height of 80 metres

Source: Windlab Systems Pty Ltd, DEWHA Renewable Energy Atlas (wind map data); Geoscience Australia of Western Australia, South Australia and western Victoria all have good wind resources. Areas with high wind potential also lie along the higher exposed parts of the Great Dividing Range in south-eastern Australia, such as the Southern Highlands and New England areas.

The New South Wales Wind Atlas (Sustainable Energy Development Authority, NSW 2002) shows that the areas with the highest wind energy potential lie along the higher exposed parts of the Great Dividing Range and very close to the coast except where there is significant local sheltering by the escarpment. The best sites result from a combination of elevation, local topography and orientation to the prevailing wind. Significantly, the map shows that some inland sites have average wind speeds comparable with those in coastal areas of southern Australia.

The Victorian Wind Atlas (Sustainable Energy Authority Victoria 2003), shows a modelled average wind speed of 6.5 m/s across the state with the highest average wind speeds (> 7 m/s) found in coastal, central and alpine regions of Victoria (figure 9.8). The atlas also presents modelled average wind speed data in relation to land title (national parks, other public land and freehold land), land use and proximity to the electricity network. Effective wind resources are defined as those located within a commercially viable distance from the electricity network. The atlas delineates corridors within 10 and 30 km of the network. It presents wind resource maps for each of the local government areas in relation to the electricity network according to land title.

Local topography and other variability in the local terrain such as surface roughness exert a major influence on wind speed and wind variability. Wind speed varies with height and with the shape and roughness of the terrain. Wind speed decreases with an increasingly rough surface cover, but can be accelerated over steep hills, reaching a maximum at the crest and then separating into zones of turbulent air flow. There are also thermal effects and funnelling which need to be considered when assessing wind resources. All of these effects impact on capacity factors (Coppin et al. 2003; ESIPC 2005). Australia's high capacity factors reflect the large development potential.

Because of these factors meso-scale maps such as figure 9.8 do not account for fine-scale topographical accelerations of the flow. In particular, the effect of any topographical feature smaller than 3 km is unlikely to be accounted for. In mountainous country, topographical accelerations (and decelerations) because of these finer scale features commonly exceed 20 per cent. As such, these maps are useful only for preliminary selection of sites: detailed assessment of wind energy resources for potential wind farm location sites requires integration of high quality monitoring measurements with a micro-scale model of wind flow incorporating the effects of topography and terrain roughness.

9.3.2 Wind energy market

The wind energy market in Australia is growing at a rapid pace, driven by an increasing emphasis on cleaner energy sources and government policies encouraging its uptake. The wind energy industry has been the fastest growing renewable energy source, largely because it is a proven technology, and has relatively low operating costs and environmental impact.

Primary energy consumption

In 2007–08, wind energy accounted for only 0.2 per cent of primary energy consumption (table 9.1). However, wind is the fastest growing energy source in Australia, increasing at an average annual rate of 69.5 per cent between 1999–00 and 2007–08.

Electricity generation

In Australia, wind energy was first utilised for electricity generation in 1994 and the industry has expanded rapidly in recent years (figure 9.9). Australia's wind electricity generation was 3.9 TWh (14.2 PJ) in 2007–08, accounting for 1.5 per cent of total electricity output in Australia.

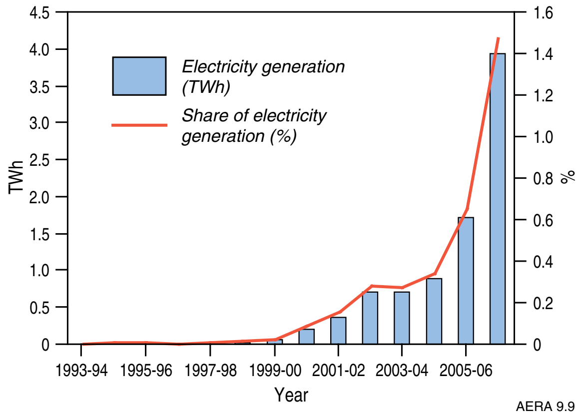

Figure 9.9 Australia's wind electricity generation

Source: IEA 2009; ABARE 2009a

Installed electricity generation capacity

In September 2009 there were 85 wind farms in Australia with a combined installed capacity of 1.7 GW (table 9.4). The majority of these power stations were located in South Australia (48 per cent), Victoria (23 per cent) and Western Australia (12 per cent) (figure 9.10). Information on recently developed wind energy projects is provided in box 9.2.

The size of wind farms is increasing, as companies with capacity to install large farms take advantage of economies of scale and capitalise on sites with high wind potential. Australia's largest wind farm is the Waubra wind farm in Victoria (192 MW), which was

Table 9.4 Australia's wind energy industry: number of farms and installed capacity, by state, 2009

State/Territory	Farms no.	Installed capacity MW	Share of total capacity %
South Australia	19	810.9	47.6
Victoria	19	383.9	22.5
Western Australia	19	202.7	11.9
New South Wales	9	149.0	8.7
Tasmania	7	143.9	8.4
Queensland	8	12.5	0.7
Northern Territory	4	0.1	0.0
Australia	**85**	**1703**	**100.0**

Source: Geoscience Australia 2009; ABARE 2009b

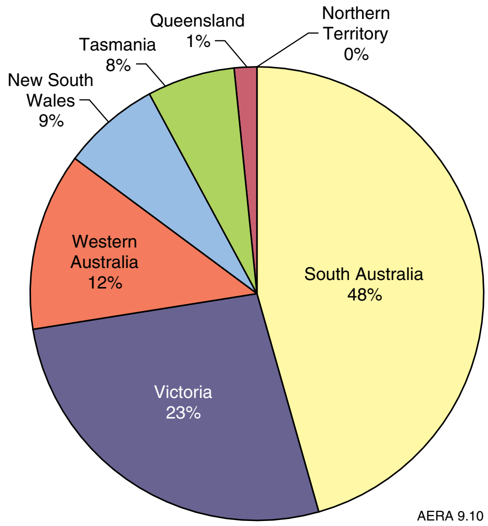

Figure 9.10 Installed wind energy capacity, by state, 2009

Source: Geoscience Australia 2009

commissioned in mid 2009, followed by Lake Bonney in South Australia (159 MW). However, wind farms larger than 200 MW and up to 1000 MW are planned or under construction. More detailed information on project developments is provided in section 9.4.2.

9.4 Outlook to 2030 for Australia's wind energy resources and market

Australia accounts for only a small share of world wind energy production (an estimated 2 per cent in 2008); however, it grew at a faster rate (69 per cent) than average between 1999–00 and 2007–08. While wind currently accounts for only 1.5 per cent of Australia's electricity generation its share is likely to increase, driven substantially by government policies such as the Australian Government's Renewable Energy Target (RET) and the fact that wind energy is a proven renewable energy technology with extremely low greenhouse gas emissions.

By 2029–30 wind energy is projected to provide about 12 per cent of Australia's electricity (ABARE 2010).

9.4.1 Key factors influencing the future development of Australia's wind resources

Worldwide, wind energy is the fastest growing form of electricity generation and is set to play an increasingly important role in the energy mix, globally as well as in Australia. It is a proven and mature technology and the output of both individual turbines and wind farms has increased significantly in the past five years. The wind energy market has reached a mature stage in some energy markets, such as in western Europe, because it is already cost competitive with other forms of electricity generation.

The expansion of wind energy in Australia is likely to be enhanced by government policies favouring low emissions, such as the RET and emissions reduction targets and the increasing cost competitiveness of wind energy. The RET will help drive the growth of renewable energy sources in the period to 2020. After 2020 the proposed emissions reduction target carbon price is projected to rise to levels that continue to drive the growth of renewable energy. Wind energy is likely to particularly benefit.

Wind is generally the most cost competitive renewable source of electricity generation behind hydro. However, it has significantly more growth potential because of the greater level of as yet unutilised resources. Its cost competitiveness will be enhanced by a reduction in the cost of turbines, particularly through low cost, high volume manufacturing in countries such as India and China, and to a lesser extent by further efficiency gains through turbine technology development.

Factors that may limit development of wind energy on a localised basis are a lack of electricity transmission infrastructure to access remote wind resources, and the intermittency and variability of wind energy. The variability of wind energy can create difficulties in integration into the electricity system where supply must balance demand in real time to maintain system stability and reliability. This becomes more of a problem as the amount of wind energy incorporated into the grid increases and can become significant in a localised context. However, at the levels of wind energy penetration projected, these issues should be effectively managed by greater geographic spread of wind resources, improvements to the response capabilities of the grid through improved forecasting, continued use of conventional fuels for base load electricity generation and increased use of gas turbines in peaking generation.

Wind energy – an increasingly cost-competitive mature low emissions renewable energy source

The rapid expansion of wind energy over the past decade is the outcome of international research and development that has resulted in major improvements in wind turbine technology.

The most significant technological change in wind turbines has been substantial increases in the size and height of the rotor, driven by the desire to access higher wind speeds (wind speed generally increases with height above the ground) and thereby increase the energy extracted. The size of the rotor is determined by the maximum aerodynamic efficiency, which is adjusted to keep the tip speed under control, and so minimise noise concerns, and to spill wind when the turbine reaches maximum output.

The size and output of wind turbine rotors has doubled over the past fifteen years (figure 9.19). For example, Australia's first large-scale grid-connected wind farm (at Crookwell, New South Wales) in 1998 comprised eight 600 kW wind turbines each with a rotor diameter of 44 metres for a combined energy output of 4.8 MW. Today most onshore wind turbine generators have a capacity of 1.5 to 2 MW; the largest wind turbines – designed for offshore sites – have a capacity of 5 MW and rotor blades up to 60 m long (120 m rotor diameter). The recently commissioned Capital Wind Farm (near Goulburn in New South Wales) comprises 67 wind turbines, each with a rating of 2.1 MW and rotor diameter of 88 metres, resulting in total installed capacity of 141 MW.

Efficiency gains through onshore turbine technology are now slowing, and further increases in cost competitiveness will be driven by reducing manufacturing costs. This is being achieved primarily through a move to low cost, high volume turbine production.

BOX 9.2 WIND PROJECTS RECENTLY DEVELOPED

Since 2005, there have been some 17 wind energy projects completed in Australia, with a combined generation capacity of around 1475 MW. Of these, seven were developed in South Australia, five in Victoria, two in Western Australia, two in New South Wales and one in Tasmania. The largest project completed was the Waubra wind farm in Victoria, completed in 2009 by Acciona Energy and ANZ Energy Infrastructure Trust.

Table 9.5 Wind projects recently developed, as at late 2009

Project	Company	State	Start up	Capacity
Cape Bridgewater	Pacific Hydro	VIC	2008	58 MW
Capital Wind Farm	Renewable Power Ventures	NSW	2009	141 MW
Cathedral Rocks	Roaring40s/Hydro Tasmania & Acciona Energy	SA	2005	66 MW
Cullerin Range Wind Farm	Origin Energy	NSW	2009	30 MW
Emu Downs	Transfield Services Infrastructure Ltd & Griffin Energy	WA	2006	79.2 MW
Hallett 1	AGL	SA	2007	94.5 MW
Lake Bonney 1	Babcock and Brown Wind Partners	SA	2005	80.5 MW
Lake Bonney 2	Babcock and Brown Wind Partners	SA	2008	159 MW
Mount Millar	Transfield Services Infrastructure Ltd	SA	2006	70 MW
Portland stage 3	Pacific Hydro	VIC	2009	44 MW
Snowtown	Wind Prospect and Trust Power	SA	2007	98.7 MW
Walkaway	Babcock and Brown Wind Partners/Alinta Ltd	WA	2005	90 MW
Wattle Point	ANZ Energy Infrastructure Trust/Wind Farm Developments	SA	2005	91 MW
Waubra	Acciona Energia/ANZ Energy Infrastructure Trust	VIC	2009	192 MW
Wonthaggi	Wind Power Pty Ltd	VIC	2005	12 MW
Woolnorth	Roaring40s/Hydro Tasmania	TAS	2007	140.25 MW
Yambuk	Pacific Hydro Ltd	VIC	2007	30 MW

Source: Geoscience Australia 2009

Cost of development

The costs specific to developing a new wind farm will vary across projects and locations. They will be influenced by a number of factors such as:

- The cost of turbines;
- Proximity to existing infrastructure;
- Ease of grid integration;
- Whether the development is onshore or offshore;
- The life of the project;
- Government policies and regulations;
- Environmental impact; and
- Community support.

These factors influence the spread of development costs across different countries (figure 9.11).

Lifecycle cost structure

The development of wind energy is relatively capital intensive compared with many other energy sources, estimated to typically comprise between 70 per cent and 80 per cent of a project's lifetime costs (Blanco 2009, Dale et al. 2004). This is primarily because of the high cost of turbines (figure 9.12) and grid integration infrastructure relative to the low variable costs. The only variable costs are operation and maintenance costs, as the resource used in electricity generation (i.e. wind) is free. Individual turbines can cost up to $3 million. A tightness in supply and high metal prices led to substantial increases in the cost of turbines in the period 2004–08 but prices for 2010 delivery have eased (Beck and Haarmeyer 2009). Figure 9.13 shows a schematic life-cycle cost structure of a typical wind farm, as estimated by Dale et al. (2004).

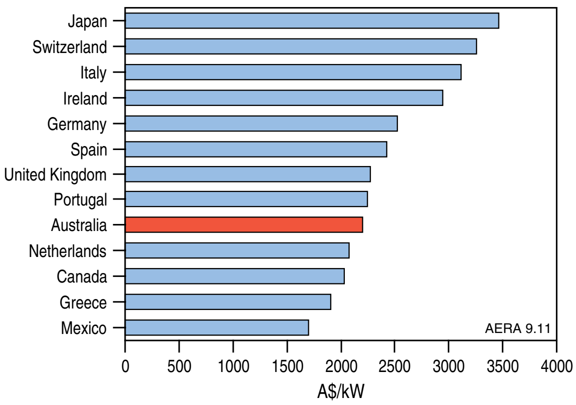

Figure 9.11 Estimated average wind energy project cost, 2007

Source: IEA 2008; ABARE 2009b

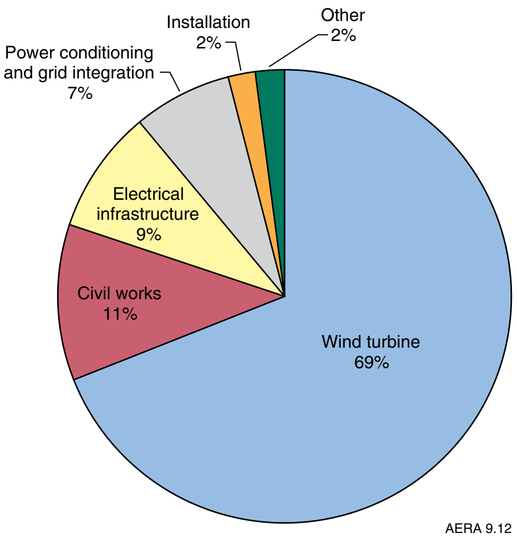

Figure 9.12 Capital costs of a typical wind farm

Source: Mathew 2006

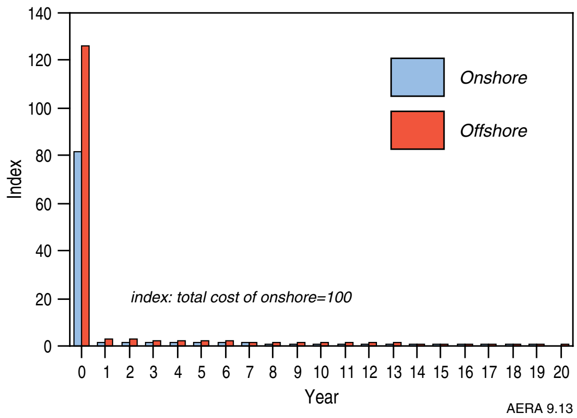

Figure 9.13 Lifecycle costs of a typical wind farm

Source: Dale et al. 2004

A wind farm's revenue stream at its most basic level is the product of the amount and price of electricity sold to the grid. Higher income streams are favoured by a higher electricity price and by larger wind farms with larger turbines (and hence greater capacity). Consequently, countries with relatively more highly developed wind energy industries typically have a combination of good wind conditions and high electricity prices. Direct subsidies and other clean energy initiatives may further influence the uptake of wind energy.

Economies of scale

At the end of 2008, small wind farms (less than 10 MW capacity) comprised 70 per cent of operating wind farms in Australia, but accounted for less than 2 per cent of Australia's wind energy capacity (figure 9.14). On the other hand, large wind farms (greater than 100 MW capacity) comprised 6 per cent of operating wind farms but accounted for around 38 per cent of Australia's wind generating capacity. Medium sized wind farms (10–100 MW capacity) accounted for the majority of wind energy capacity in Australia, around 60 per cent. Large operations account for a much greater proportion of proposed operations (tables 9.7 and 9.8; ABARE 2009b).

The increasingly large size of wind farms reflects the economies of scale to be gained through larger operations. Heavy utilisation of sites with high wind potential and consolidation of generating technology will significantly reduce grid integration costs and maximise the economic gains from wind energy. The economies of scale can be seen by the lower cost per kWh of larger wind farms (figure 9.15). In addition, larger firms are more able to cover the considerable fixed costs of setting up larger wind farms, which is reflected in a trend toward industry consolidation.

Past barriers to the development of larger installations have been the large up-front capital costs and the associated uncertainty about achieving secure contracts for the electricity generated. However, this barrier is declining in importance because of the increasing demand for low emission renewable energy. As returns to investments are proven and become more secure, larger investments are emerging.

Cost competitiveness

On a levelised cost of technology basis (including capital, operating, fuel, and maintenance costs, and capacity factor) wind energy compares favourably with traditional sources of electricity generation, such as coal, oil, gas, nuclear and biomass (figures 2.18, 2.19, Chapter 2). Moreover, its uptake will be favoured by the RET. Lower manufacturing costs together with improvements in turbine efficiency and performance, and optimised use of wind sensing equipment are expected to decrease the cost of wind technology in the future.

Time to develop

The development process after feasibility has been ascertained is relatively simple, comprising an approval stage and a building stage. The length of the approval stage can vary widely, depending on the relevant authorities' requirements and the complexity of the approval process. Construction time varies depending on a number of factors but is short compared with many other forms of electricity generation. For example, the 192 MW Waubra wind farm began construction in November 2006 and was completed in May 2009 – a total of about 2.5 years. Construction of smaller projects can be significantly quicker: the 30 MW Cullerin Range Wind Farm took 1 year, after commencing in June 2008 it was completed in June 2009. Because of additional foundation and grid integration requirements, installation of offshore wind farms involves longer building times. Remoteness and complexity of terrain will also affect the building time. Conversely, one advantage of wind energy is that, compared with many other renewable technologies, it is a proven technology that is relatively straightforward to build and commission.

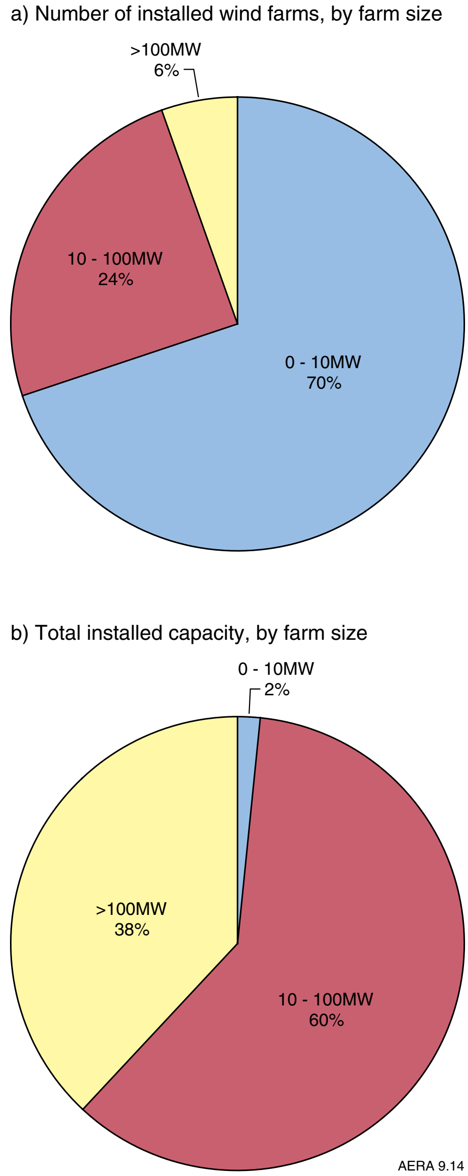

Figure 9.14 Current wind energy installations in Australia, by farm size

Source: Geoscience Australia 2009

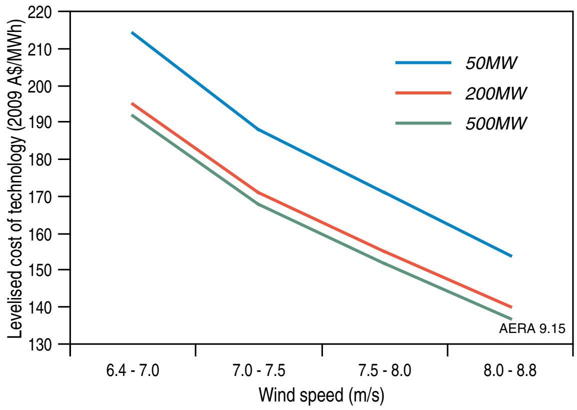

Figure 9.15 Wind levelised cost of technology, by farm size

Note: This EPRI technology status data enables the comparison of technologies at different levels of maturity. It should not be used to forecast market and investment outcomes.

Source: EPRI technology status data

Policy environment

The current and prospective policy environments within which a wind farm is operating are central to the effectiveness and competitiveness with which it operates. Direct support through subsidisation or favourable tax policies (as in some countries), or indirect support for renewables from costs imposed on greenhouse gas emissions will enhance the competitiveness of wind energy and other renewables sources of energy. The operation of wind turbines produces no carbon dioxide emissions, and emissions involved in the development stage are modest by comparison with electricity generation from other sources. In Australia growth of wind energy is favoured by the Renewable Energy Target and proposed reductions in carbon emissions.

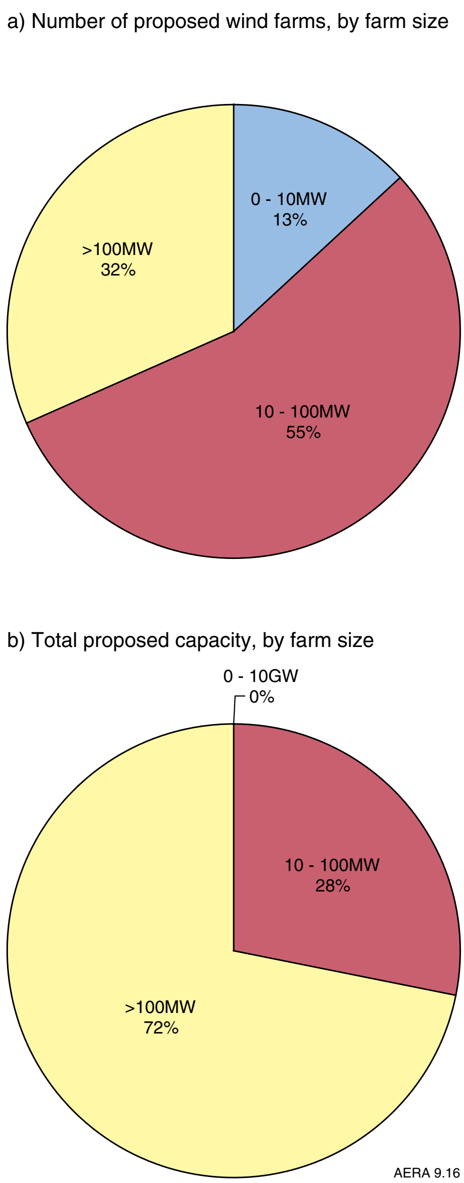

Figure 9.16 Proposed wind energy installations by farm size

Source: Geoscience Australia 2009

Grid integration – managing an intermittent source of energy

Wind is a highly variable resource and so, therefore, is wind energy production. The high ramp rate of wind energy production is an associated and equally important characteristic, particularly in integrating the electricity produced into the electricity grid. Because wind energy increases more than proportionately with wind speed, electricity generation from wind energy can increase very rapidly (point A to B in figure 9.17). Similarly, if wind speeds exceed the turbine rating the turbine shuts down and electricity generation can drop from maximum to zero very quickly (point C to D). The variability and intermittency of wind energy needs to be matched by other fast response electricity generation capacity, or demand response. In practice this is met by complementary electricity generation capacity, typically hydro energy or increasingly gas.

Because of wind energy's inherent supply intermittency and variability, with electricity generation fluctuating according to the prevailing weather conditions, season and time of day, the penetration of wind energy in the Australian market will depend in part on improved grid management practice. A range of initiatives is being taken to enhance grid responsiveness (AER 2009). An important factor in this process is the installation of sufficient capacity to effectively manage increased supply volatility.

Grids dominated by electricity generated from conventional fuels can face difficulties in dealing with renewables other than hydro and tend to be limited to 10–20 per cent penetration by power quality issues, installed capacity and current grid management techniques. Given that wind energy accounted for only 1.5 per cent of Australia's total electricity generation in 2007–08, however, this has only been an issue at a localised level, where wind energy penetration can be much higher. Wind accounts for around only 4 per cent of registered capacity in the National Electricity Market (NEM) but has a significantly higher share in South Australia at 20 per cent (AER 2009).

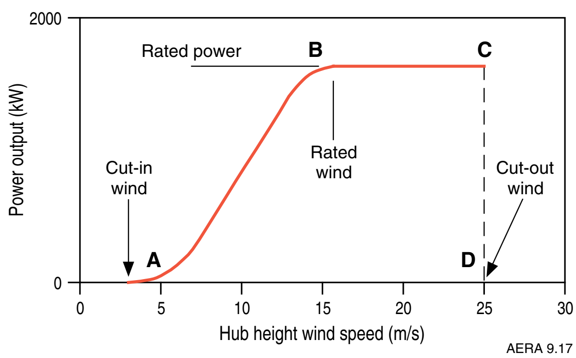

Figure 9.17 Power curve and key concepts for a typical wind turbine

Source: Ackermann 2005

The limits for a particular grid are determined by a number of factors, including the size and nature of existing connected generating plants and the capacity for storage or demand management. In grids with heavy fossil fuel reliance and sufficient hydro for balancing, wind energy penetrations of less than 10 per cent are manageable; penetration levels above 20 per cent may require system and operational changes. Gas-fired electricity generation using gas turbines, as an alternative fast response energy source, is likely to play an increasingly important role as the proportion of wind and other intermittent renewable energy used increases (AER 2009). Augmentation of the grid will also be required (AEMO 2009).

Accurate and timely wind forecasting using a range of new techniques and real-time wind and generation modelling will also enhance wind energy penetration and grid integration (Krohn et al. 2009). The Wind Energy Forecasting Capability (WEFC) system will produce more accurate forecasts of wind electricity generation over a range of forecast timeframes that can be used by the Australian Energy Market Operator (AEMO), wind farms and other market participants to better appreciate and manage the balance between supply and demand and the interaction between baseload and peakload generation.

In essence, an 'intelligence' layer is being added to the core transmission and distribution systems. Research into Smart Grids – automated electricity systems that are able to automatically respond to changes in supply from renewables and fluctuations in electricity demand – is being conducted in a number of countries, including Australia. Smart grids allow real-time management and operation of the network infrastructure. The Australian Government has committed $100 million to trial smart grid technologies.

Various other experimental technologies are being explored, including storage technologies and hybrid energy installations. The Australian Government's Advanced Electricity Storage Technologies program is supporting the development and demonstration of efficient electricity storage technologies for use with variable renewable generation sources, such as wind, in order to increase the ability of renewable energy-based electricity generation to contribute to Australia's electricity supply system. The advanced storage technologies include, but are not limited to, electro-mechanical, chemical and thermal battery systems.

A report by the Australian Energy Market Commission (AEMC 2009) recognised the need for increased flexibility and further expansion of the electricity transmission grid into new areas not previously connected to allow for an expanded role of renewable energy sources in the future. It suggests greater access to renewable resources clustered in remote geographic areas through development of connection 'hubs' or scale efficient network extensions. It also noted that expansion of gas-fired generation to back up renewable generation, such as wind, would place a greater demand for gas supply and pipeline infrastructure and lead to a greater convergence of the gas and electricity markets.

With the possible exception of localised areas with significantly higher than average wind resource (such as in South Australia and Western Australia), limits which place economic grid connection at risk are not likely to be reached in the outlook period.

Offshore wind energy developments

Because sites with the highest wind energy potential tend to be developed first, newer wind farms are likely to be sited in areas with progressively lower capacity factors. There has been some evidence of this in Europe, where land limitations have resulted in a declining average capacity factor. It has provided significant incentive to develop offshore sites.

Currently, development of wind farms offshore are limited by the high costs of offshore foundations and high costs of grid connection. Offshore locations also considerably raise the costs of operation and maintenance. However, because of substantially higher wind velocities, and therefore wind energy potential, compared with onshore sites, research and development into new technologies to increase the competitiveness of offshore wind farms is continuing. Offshore wind turbines are typically larger than those onshore to balance the increased costs of offshore marine foundations and submarine electric cables. Currently commercial, offshore wind farms are installed at shallow water depths (up to 50 m) with foundations fixed to the seabed but large scale floating turbines using ballast tied to the sea floor with cables are being tested. If successful this will allow offshore deployment in water more than 100 m deep.

Offshore sites are more important in countries with significant land access limitations, most notably in western Europe. Because Australia has sufficient onshore sites with high potential, offshore sites are unlikely to be developed in the short term. Australia's offshore sites are likely to be high cost due to ocean depth.

Electricity transmission infrastructure – a potential long term constraint

Proximity to a major energy load centre is an important element in a wind farm's economic viability, because the costs of transmission infrastructure and energy losses in transmission increase with distance from the grid. Reflecting this, wind farm developments to date have mostly been in close proximity (less than 30 km) to the grid (figure 9.18). As the size of wind farms has increased, so has the distance from the grid, with some proposed up to 100 km from the grid. The increased costs

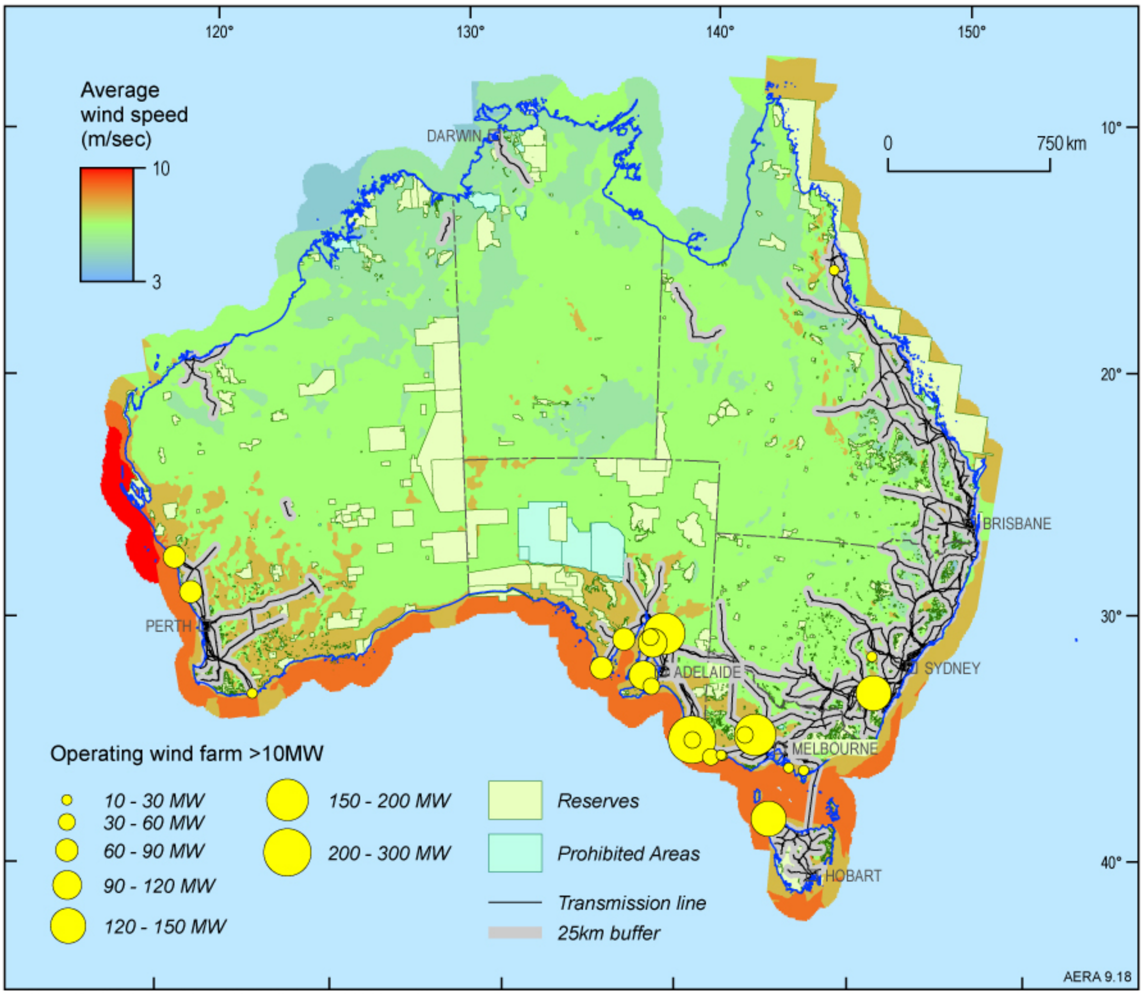

Figure 9.18 Wind energy resources in relation to reserved land and prohibited areas and the transmission grid. A 25 km buffer zone is shown around the electricity transmission grid

Source: Windlab Systems Pty Ltd, DEWHA Renewable Energy Atlas (wind map data); Geoscience Australia

and transmission losses involved impact significantly on evaluation of the cost competitiveness of the wind farm overall, and are a key factor in project evaluation.

Development of remote wind energy resources will depend on extensions to the existing transmission grid. This is demonstrated by the significant reduction of the area with good wind resources (7 m/s and greater shown in figure 9.18) from about 600 000 km^2 to about 3300 km^2 when constrained to within 100 km of the existing electricity transmission grid (66 kV and greater). The actual area available for wind farm development is significantly less than this because of other limitations such as other competing land uses, forest cover, access, and local planning and zoning laws (see for example, SEAV 2003).

Social and environmental issues – potential local constraints

Although the low level of environmental impact has been a major driver of wind farm development, there are social and environmental aspects of its operation which have attracted criticism. The most common criticisms of wind farm developments are on the basis of aesthetics, low frequency noise pollution and impacts on local bird populations.

Modern wind turbines can generate noise across the frequency range of human hearing (20 to 20 000 Hertz) and extending to low frequency (in the range of 10 to 200 Hertz) and even infrasound (in the range of 20 Hz down to 0.001 Hz) levels, below the detection limit of the human ear. Concerns have been expressed that low frequency noise emitted by wind turbines can cause illness to those living in close proximity to wind turbines. However, research has shown that the levels of low frequency noise and infrasound emitted by modern wind turbines are below accepted thresholds (British Wind Energy Association 2005). There is a detailed approval process for every wind farm development which includes rigorous noise assessment. Compliance is required with relevant state Environmental Protection Agency guidelines and regulation.

Certified Wind Farms Australia (CWFA) was instituted to provide an auditable social and environmental

BOX 9.3 THE WIND TURBINE – A MAJOR TECHNOLOGICAL DEVELOPMENT

The majority of wind turbines are based on the Danish three blade design. This design differs from traditional windmills as the force from high velocity winds could potentially exceed the fatigue levels acceptable for components of the turbine. Therefore, instead of many broad, closely spaced blades, three long narrow blades achieve a balance between wind captured and an ability to manage extreme wind volatility (DWIA 2009).

Wind turbines capture wind energy within the area swept by their blades. The blades in turn drive a generator to produce electricity for export to the grid. The most successful design uses blades which generate 'lift' causing the rotor to turn. Some smaller turbines use 'drag' but they are less efficient. The common lift-style blades have a maximum efficiency of around 59 per cent, within the limits imposed by the designed maximum blade speed. Most modern wind turbines start producing energy at wind speeds of around 4 m/s, reach maximum energy at about 12-14 m/s, and cut out at wind speeds above 25 m/s.

Other considerations of turbine design include spacing between turbines, whether they are oriented upwind or downwind and the use of static or dynamic rotor designs. In each case a trade-off between size, cost, efficiency, aesthetics and a range of other factors is considered in the design of each farm.

Technology development has played an important role in increasing the competitiveness of wind energy in the electricity generation market. The size of wind turbines has reached a plateau after rising exponentially (figure 9.19). The energy output increases with the rotor swept area (rotor diameter squared) but the volume of material (cost and mass) increases in proportion to the cube of the rotor diameter (USDOE 2008).

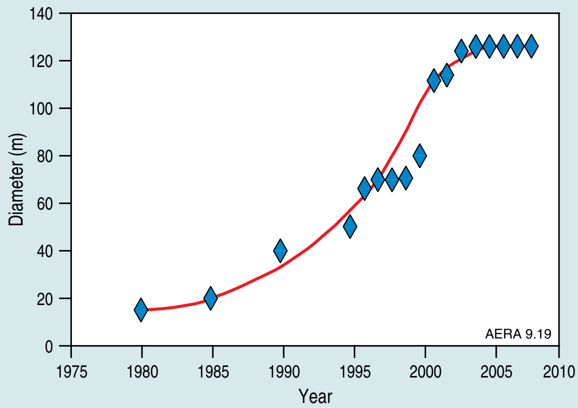

Figure 9.19 Increasing size of wind turbines over time

Source: Windfacts 2009

Until now, the additional benefits of size increases have outweighed the additional costs, which have resulted in the size of turbines increasing rapidly. While turbines are expected to continue to get bigger, the additional returns from those size increases are likely to diminish. Research into rotor design and materials is aimed at reducing loads on blades to allow development of larger, lighter rotors and taller towers with higher capacity factors. Wind turbines with capacities up to 7.5 MW are being considered for offshore deployment.

Table 9.6 Outlook for wind energy in Australia

	unit	2007–08	2029–30
Primary energy consumption[a]	PJ	14.2	160
Share of total	%	0.2	2.1
Average annual growth, 2007–08 to 2029–30	%	-	11.6
Electricity generation			
Electricity output	TWh	4	44
Share of total	%	1.5	12.1
Average annual growth, 2007–08 to 2029–30	%	-	11.6

a Energy production and primary energy consumption are identical
Source: ABARE 2010

sustainability framework for the wind energy industry. This aims to provide a basis for continual assessment and improvement of best practice within the industry, and a mechanism for assessment of wind farm projects against these benchmarks.

9.4.2 Outlook for wind energy market

Wind is expected to play an increasingly important role in the energy mix of many countries, including Australia. It will be essential in meeting the RET, and is expected to underpin a rapidly expanding renewables sector. In the latest ABARE long-term energy projections which are based on the RET and a 5 per cent emissions reduction target, wind energy is projected to generate 44 TWh of electricity in 2029–30, accounting for 12.1 per cent of Australia's electricity generation, and 2.1 per cent of Australia's total primary energy consumption (table 9.6). This represents 12 per cent average annual growth over the period to 2029–30.

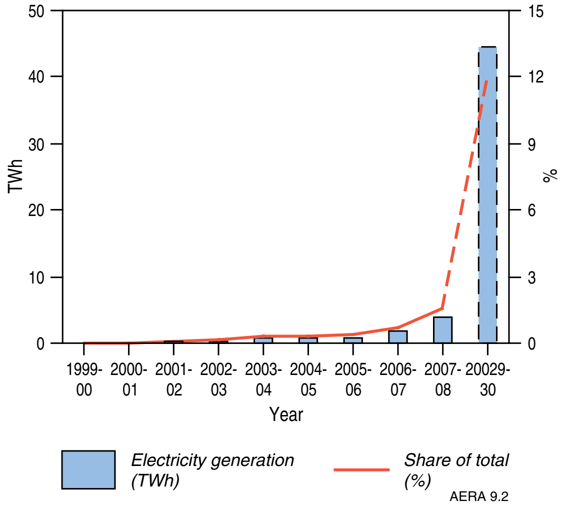

Figure 9.20 Projected Australian wind energy production and wind share of electricity generation

Source: ABARE 2010

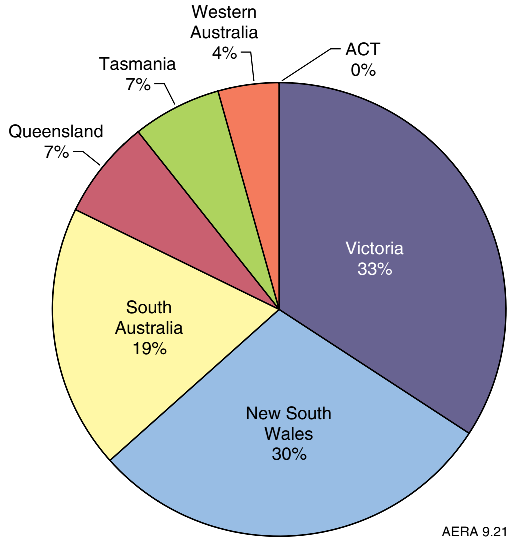

Figure 9.21 Proposed wind energy capacity by state

Source: ABARE 2009b

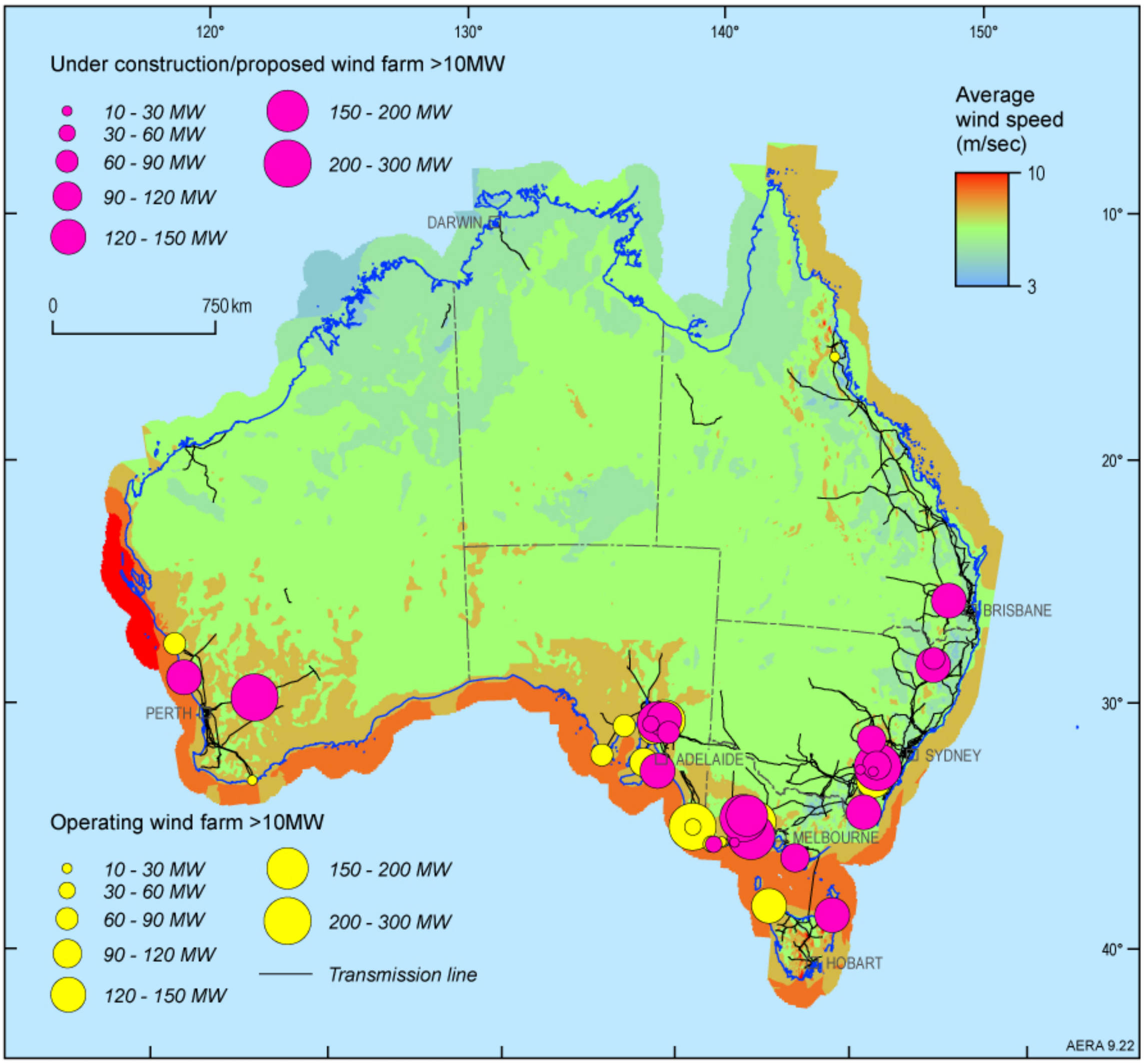

Figure 9.22 Proposed development projects

Source: ABARE 2009b; Windlab Systems Pty Ltd, DEWHA Renewable Energy Atlas (wind map data); Geoscience Australia

Wind energy is projected to be the second fastest growing energy industry after geothermal over the outlook period to 2029–30, reflecting the relatively low base from which it is growing and the relative maturity of the technology compared with other renewable energy sources. It is projected to overtake hydro electricity production within the outlook period, to become the largest renewable source of electricity generation in Australia.

Proposed development projects

The majority of the planned expansions in wind energy capacity are expected to occur in southern regions of Australia with high wind energy potential. Overall, a further 11.3 GW of wind energy capacity has been proposed, with the bulk of this in Victoria (34 per cent), New South Wales (30 per cent) and South Australia (19 per cent), taking account of both wind energy potential in these areas and constraints imposed by the transmission grid (figure 9.21).

As of October 2009, there were eight wind projects in Australia at an advanced stage of development. In total, they have a planned capacity of 733 MW, and a combined capital expenditure of $1.8 billion. Of the eight projects, three have a planned capacity of over 100 MW; the remainder vary between 39 and 92 MW (table 9.7).

Wind projects at a less advanced stage of development had a total of almost 11 GW of additional capacity (table 9.8). Although the development of these projects is not certain, as they are subject to further feasibility and approval processes, it is of particular note that the average capacity is 149 MW, compared with an average capacity of 92 MW for projects at an advanced stage of development. The most significant of these prospective projects is the Silverton wind farm in New South Wales. This is the largest proposed wind farm development, both in terms of additional capacity (1000 MW) and capital expenditure ($2.2 billion). It is currently planned to be commissioned in 2011. Reflecting high wind potential, the majority of wind energy projects are planned for the south-east region of the country.

Table 9.7 Projects at an advanced stage of development, as of October 2009

Project	Company	Location	Status	Start up	Capacity	Capital Expenditure
Clements Gap	Pacific Hydro	30 km S of Port Pirie, SA	Under construction	early 2010	57 MW	$135 m
Crookwell 2	Union Fenosa Wind Australia	14 km SE of Crookwell, NSW	Under construction	2011	92 MW	$238 m
Hallett 2	Energy Infrastructure Trust	20 km S of Burra, SA	Under construction	late 2009	71 MW	$159 m
Hallett 4 (North Brown Hill)	Energy Infrastructure Investments	12 km SE of Jamestown, SA	Under construction	2011	132 MW	$341 m
Lake Bonney stage 3	Infigen Energy	2 km E of Lake Bonney, SA	Under construction	2010	39 MW	na
Musselroe	Roaring 40s	Cape Portland, Tas	Under construction	2011	168 MW	$425 m
Oaklands Wind Farm	AGL/ Windlab Systems	5 km S of Glenthompson, Vic	Under construction	2011	63 MW	$200 m
Waterloo stage 1	Roaring 40s	30 km SE of Clare, SA	Under construction	2010	111 MW	$300 m

Source: ABARE 2009b

Table 9.8 Projects at a less advanced stage of development, as of October 2009

Project	Company	Location	Status	Start up	Capacity	Capital Expenditure
Allendale	Acciona Energy	20 km S of Mt Gambier, SA	Govt approval under way	na	70 MW	$210 m
Ararat Wind Farm	Renewable Energy Development Australia	7 km N of Ararat, Vic	Govt approval under way	2011	225 MW	$350 m
Arriga	Transfield Services	50 km SW of Cairns, Qld	Prefeasibility study under way	na	130 MW	na

Project	Company	Location	Status	Start up	Capacity	Capital Expenditure
Badgingara Wind Farm	Griffin Energy/ Stanwell Corporation	200 km N of Perth, WA	Feasibility study under way	2010	130 MW	na
Bald Hills Wind Farm	Mitsui	170 km SE of Melbourne, Vic	Govt approval received	2011	104 MW	na
Barn Hill	Transfield Services	Barn Hill, SA	Govt approval received	2010	130 MW	$300 m
Baynton	Transfield Services	80 km N of Melbourne, Vic	Feasibility study under way	2013–14	130 MW	na
Ben Lomond Wind Farm	AGL	62 km N of Armidale, NSW	Govt approval under way	na	150 MW	$300 m
Ben More	Transfield Services	150 km NW of Melbourne, Vic	Feasibility study under way	2014	90 MW	na
Berrybank Wind Farm	Union Fenosa Wind Australia	60 km E of Mortlake, Vic	Govt approval under way	2011	180–250 MW	$484 m
Boco Rock Wind Farm	Wind Prospect	146 km SW of Nimmitabel, NSW	Govt approval under way	2012	270 MW	$750 m
Carmody's Hill Wind Farm	Pacific Hydro	18 km N of Mt Misery, SA	Govt approval under way	na	140 MW	$350 m
Cattle Hill Wind Farm	NP Power	5 km E of Lake Echo, Tas	EIS under way	2011	150–210 MW	na
Collector	Transfield Services	50 km NE of Canberra, NSW	Feasibility study under way	2013	150 MW	na
Collgar Wind Farm	Investec Bank/ Windlab Systems	25 km SE of Merredin, WA	Govt approval received	mid 2011	220 MW	$600 m
Conroy's Gap Wind Farm	Origin Energy	17 km W of Yass, NSW	Govt approval received	na	30 MW	na
Cooper's Gap Wind Farm	AGL/ Windlab Systems	65 km S of Dalby, Qld	Govt approval under way	2011	440 MW	$1.2 b
Crowlands Wind Farm	Pacific Hydro	30 km NE of Ararat, Vic	Govt approval under way	na	126 MW	$360 m
Crows Nest Wind Farm	AGL	43 km N of Toowoomba, Qld	Feasibility study under way	na	150 MW	$405–435 m
Darlington Wind Farm	Union Fenosa Wind Australia	5 km E of Mortlake, Vic	Feasibility study under way	2012	270–450 MW	$720 m
Drysdale Wind Farm	Wind Farm Developments	3 km N of Purnim, Vic	Govt approval received	2011	30 MW	$60–100 m
Flyers Creek Wind Farm	Flyers Creek Wind Farm	20 km S of Orange, NSW	Planning approval under way	na	80–100 MW	$160–200 m
Glen Innes Wind Farm	Glen Innes Wind Power	Waterloo Range, NSW	EIS under way	na	44–81 MW	$150 m
Gullen Range Wind Farm	Epuron	25 km NW of Goulburn, NSW	Govt approval under way	2010	248 MW	$250 m
Gunning	Acciona Energy	40 km E of Goulburn, NSW	Govt approval received	na	46.5 MW	$139.5 m
Hallett 3 (Mt Bryan)	AGL	Hallett, SA	Feasibility study under way	2011	80 MW	$216–232 m
Hallett 5 (The Bluff)	AGL	12 km SE of Jamestown, SA	Feasibility study under way	na	50 MW	$135–145 m
Hawkesdale Wind Farm	Union Fenosa Wind Australia	35 km N of Point Fairy, Vic	Govt approval received	2011	62 MW	$150 m
High Road	Transfield Services	70 km SW of Cairns, Qld	Feasibility study under way	2012	50 MW	na
Keyneton	Pacific Hydro	10 km SE of Angaston, SA	Prefeasibility study under way	na	120 MW	na
Kongorong	Transfield Services	30 km SW of Mt Gambier, SA	Prefeasibility study under way	na	120 MW	na
Kulpara	Transfield Services	100 km NW of Adelaide, SA	Prefeasibility study under way	na	80 MW	na
Lal Lal Wind Farm	West Wind Energy	25 km SE of Ballarat, Vic	Govt approval received	2012	131 MW	$320–360 m
Lexton Wind Farm	Wind Power Pty Ltd	44 km NW of Ballarat, Vic	Govt approval received	2011	38 MW	$110 m
Lincoln Gap Wind Farm	NP Power/ Infigen Energy	near Port Augusta, SA	Govt approval received	2011	118 MW	na

Project	Company	Location	Status	Start up	Capacity	Capital Expenditure
Macarthur Wind Farm	AGL/ Meridian Energy	Macarthur, Vic	Govt approval received	2010	330 MW	$850 m
Milyeannup Wind Farm	Verve Energy	20 km E of Augusta, WA	Govt approval under way	2011	55 MW	$160 m
Moorabool Wind Project	West Wind Energy	25 km SE of Ballarat, Vic	Feasibility study under way	2014	220–360 MW	$600 m
Mortlake Wind Farm	Acciona Energy	5 km S of Mortlake, Vic	Govt approval under way	0	144 MW	$432 m
Morton's Lane	NewEn Australia	100 km N of Warrnambool, Vic	Govt approval received	na	30 MW	$60 m
Mount Gellibrand Wind Farm	Acciona Energy	15 km NE of Colac, Vic	Govt approval received, on hold	na	232 MW	$696 m
Mount Hill	Transfield Services	80 km NE of Port Lincoln, SA	Prefeasibility study under way	na	80 MW	na
Mount Mercer Wind Farm	West Wind Energy	30 km S of Ballarat, Vic	Govt approval received	2010	131 MW	$320–360 m
Mumbida	Verve Energy	40 km S of Geraldton, WA	Feasibility study under way	2012	90 MW	$250 m
Myponga	TrustPower	50 km S of Adelaide, SA	Govt approval received	na	40 MW	na
Naroghid Wind Farm	Wind Farm Developments	10 km N of Cobden, Vic	Govt approval received	2011	42 MW	$60–100 m
Nilgen Wind Farm	Pacific Hydro	9 km E of Lancelin, SA	Govt approval under way	na	100 MW	$280 m
Orford	Future Energy	28 km NW of Port Fairy, Vic	Feasibility study under way	na	100 MW	na
Paling Yards	Union Fenosa Wind Australia	84 km N of Goulburn, NSW	Feasibility study under way	2012	100–125 MW	$312 m
Portland stage 4	Pacific Hydro	Cape Nelson North and Cape Sir William Grant, Vic	Govt approval under way	na	54 MW	na
Robertstown Wind Farm	Roaring 40s	123km N of Adelaide, SA	Planning approval under way	2014	70 MW	$175 m
Ryan Corner Wind Farm	Union Fenosa Wind Australia	10 km NW of Port Fairy, Vic	Govt approval received	2011	136 MW	$327 m
Sapphire Wind Farm	Wind Prospect	Inverrel, NSW	Govt approval under way	2012	356–485 MW	$925–1250 m
Sidonia Hills Wind Farm	Roaring 40s	10 km NE of Kyneton, Vic	Planning approval under way	2012	68 MW	$175 m
Silverton Wind Farm	Silverton Wind Farm Developments	25 km NW of Broken Hill, NSW	Govt approval received	2011	1000 MW	$2.2 b
Snowtown stage 2	TrustPower	5 km W of Snowtown, SA	Govt approval received	2011	212 MW	na
Stockyard Hill Wind Farm	Origin Energy	35 km W of Ballarat, Vic	Planning approval under way	na	484 MW	$1.4 b
Stony Gap Wind Farm	Roaring 40s	120 km N or Adelaide, SA	Planning approval under way	2013	100 MW	$250 m
Taralga	RES Australia	3 km E of Taralga, NSW	Govt approval received	2011	110–165 MW	na
Tarrone	Union Fenosa Wind Australia	25 km N of Port Fairy, Vic	Feasibility study under way	2013	30–40 MW	$90 m
The Sisters Wind Farm	Wind Farm Developments	12 km S of Mortlake, Vic	Planning approval under way	2013	30 MW	$63 m
Tuki Wind Farm	Wind Power	37 km N of Ballarat, Vic	Prefeasibility study under way	na	38 MW	na
Vincent North	Pacific Hydro	Yorke Peninsula, SA	Govt approval under way	na	30 MW	$100 m
Waubra North	Acciona Energy	8 km NE of Waubra, Vic	Feasibility study under way	na	75 MW	na
White Rock Wind Farm	Eureka Funds Management	100 km NE of Launceston, Tas	Prefeasibility study under way	2014	400 MW	na
Woodlawn Wind Farm	Acciona Energy	40 km S of Goulburn, NSW	Govt approval received, on hold	na	50 MW	$150 m

Project	Company	Location	Status	Start up	Capacity	Capital Expenditure
Woolsthorpe Wind Farm	Wind Farm Developments	2 km W of Woolsthorpe, Vic	Govt approval received	2011	40 MW	$60–100 m
Woorndoo (Salt Creek)	NewEn Australia	100 km SW of Ballarat, Vic	Govt approval received	na	30 MW	$60m
Worlds End	AGL	Burra, SA	Feasibility study under way	na	180 MW	$486–522 m
Yaloak Wind Farm	Pacific Hydro	35 km E of Ballarat, Vic	Planning approval under way	na	30 MW	na
Yass Wind Farm	Epuron	20 km W of Yass, NSW	Govt approval under way	na	364–600 MW	$800 m

Source: ABARE 2009b

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