

Renewable power density in Australia: wind vs solar

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Wind power density

Average wind power per square metre, for average wind speed, v , and air density $\rho = 1.3 \text{ kg/m}^3$ is given by:

$$\langle P_{in} \rangle = \frac{1}{2} \rho v^3$$

Harvesting wind power

A wind turbine with a blade of diameter, d , can extract power equal to:

$$P_t = \eta \times \frac{\pi}{4} d^2 \times P_w$$

where η is the efficiency that the turbine turns wind power into electrical power, taken to be $\eta = 50\%$, and the second term in the area swept by the blade.

Turbines must be at least $(5d)^2$ away from each other to avoid shading. The power per unit area that can be harvested is then:

$$P_{out} = \eta \frac{\frac{\pi}{8} \rho v^3 d^2}{(5d)^2} = \eta \frac{\pi \rho v^3}{200} = \eta \times \frac{\pi}{100} \times \langle P_{in} \rangle$$

Note that this is independent of turbine diameter and sensitively dependent on the wind speed.

(see for example: *Sustainable Energy - without the hot air*, pg 263, by David JC MacKay
https://www.withouthotair.com/cb/page_263.shtml)

Solar power density

There is no well define average solar power as the amount of light hitting the earth varies regularly over the day and the year. Instead we define a standard irradiance called the AM1.5g spectra:

$$P_{in} = P_{AM1.5g} = 1 \text{ kW/m}^2$$

This irradiance will only be a good estimate around midday on a clear sunny day at certain latitudes on earth. It is a relatively good estimate for most parts of Australia. The specifications of the standard reference spectra can be found here:

[https://www2.pvlighthouse.com.au/resources/courses/altermatt/The%20Solar%20Spectrum/The%20Global%20standard%20spectrum%20\(AM1-5g\).aspx](https://www2.pvlighthouse.com.au/resources/courses/altermatt/The%20Solar%20Spectrum/The%20Global%20standard%20spectrum%20(AM1-5g).aspx)

We know that the sun is only high in the sky for part of the day, so a capacity factor is sometimes used to estimate the average power spread over the day or year. Generally, capacity factors of around 20% are used.

Harvesting solar power

The efficiency of a solar module, η , is quoted with reference to the standard spectrum, and is typically between $15\% > \eta > 17\%$ for modules in a large solar farm. A performance factor PF takes into account additional losses due to the cabling, invertors, and other non-ideal conditions at the site of the solar farm; this is generally 80-90%. The power per unit area that can be harvested is then:

$$P_{out} = \eta \times PF \times P_{AM1.5g}$$

Average yearly energy density: Watt-hours vs Watt

As both wind and solar power is variable, it is more useful to look at average yearly energy densities that instantaneous average power. We can convert then from average power density, P_{in} [W/m^2] to average yearly energy density, E_{in} , measured in Watt-hours per annum per area [$Whpa/m^2$] by multiplying by the number of hours in a year ($365.24 \times 24 = 8766$).

For wind power, the average wind speed at 100 m above land (about the height of a modern wind turbine hub) in Australia is taken to be $v = 6 - 9 m s^{-1}$ from <https://nationalmap.gov.au/renewables/>

For solar power, we use the measured average annual sum of irradiation (GHI) in Australia, taken to be 1700-2200 $kWhpa/m^2$ from <https://solargis.com>. (Note that we can calculate an average input power density from this data, by dividing by the hours in a year.)

The average yearly energy output density is then calculated replacing P_{in} [W/m^2] with E_{in} [$Whpa/m^2$] in the equations above.

The results for the input power densities, and average yearly input/output energy densities are given in the table below for both solar and wind.

Typical Results for Australia	Wind	Solar
Average input power density [kW/m^2]	0.14-0.47	0.19-0.25
Efficiency of conversion	$\eta \times \frac{\pi}{100} = 0.016$	$\eta \times PF = 0.14$
Average yearly energy input density [$kWhpa/m^2$]	1230-4150	1700-2200
Average yearly energy output density [$kWhpa/m^2$]	20-66	221-286

From the table we can see that the average power density of wind and solar in Australia is comparable. However, due to the higher efficiency of energy harvesting, solar power has a higher yearly energy output density, by as much as an order of magnitude under some conditions.