CO_2 avoidance cost with wind energy in Australia and carbon price implications

By
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Introduction

This paper presents a simple analysis to estimate the amount of CO_2 emissions avoided by wind generation and the cost per tonne avoided as wind penetration increases from 0% to 20%. The carbon price implications are discussed.

The analysis is based on a paper by Herbert Inhaber (2011)[1]. The analysis is for Australia's National Electricity Market.

Emissions Avoided by wind generation

Herbert Inhaber (2011) reviewed eleven studies of CO_2 savings by wind generation and concludes wind generation becomes less effective at reducing CO2 emissions as wind penetration increases. That is, wind generation avoids less CO_2 as wind energy's share of total generation increases. Inhaber explains:

> *"as wind penetration increases, the CO2 reduction will gradually decrease due to cycling of the fossil fuel plants that make up the balance of the grid."*

Below is an extract from the "Conclusions" and "Uncertainties" sections of Inhaber's paper [in this extract, references to 'Fig. 3' are to the figure in Inhaber's paper, which is reformatted and called 'Figure 1' here):

> "*There are considerable uncertainties about how fast this decrease occurs, and the curve in Fig. 3 should be taken as only suggestive. However, the arc seems to be a mirror image of a sigmoid curve, with an equation*
>
> $$Q = \frac{200}{1+e^{cx}}$$
>
> *where Q is the CO2 reduction in percent, x is the wind or intermittent renewable penetration of the grid in percent, and c is a constant, of the order of 0.2 in Fig. 3.*

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Figure 1: [Inhaber's Fig. 3 reformatted to make it easier to interpret. In Inhaber's paper, Fig. 3 is presented with log-scale on the vertical axis.]

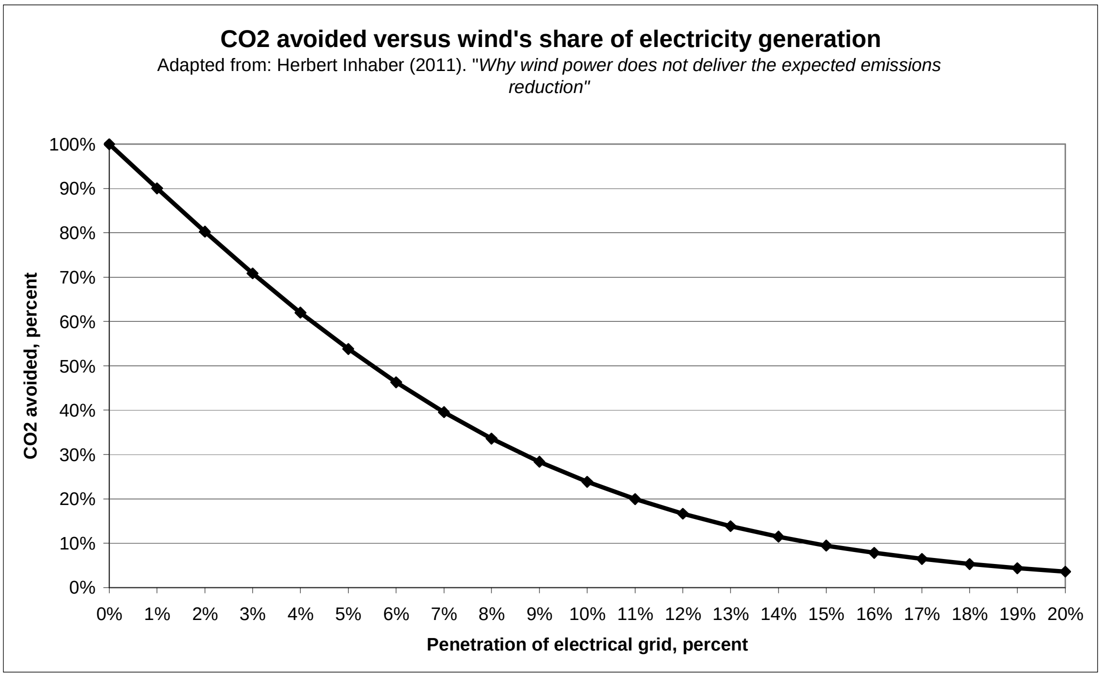


Fig. 3. *A schematic graph of CO2 reductions as a function of wind (or other intermittent renewables) penetration into an electrical grid. Penetration is defined as the average fraction of energy contributed by wind to overall energy consumption. […]*

5. Uncertainties

There are considerable uncertainties in developing a curve of this type. A few of the many, not necessarily in order of importance, are:
(a) The mix of fossil fuels used in the grid and the type of gas turbines in particular;
(b) Some of the literature on wind is of a polemic nature, either advocating its widespread use or pointing out its deficiencies. Care has to be taken to concentrate on the facts and leave opinions aside;
(c) Whether renewable energy is exported to other countries, as in the case of Denmark [15]. This could skew results;
(d) The number of cycles of the fossil fuel sources that take place over time;
(e) What fraction of fossil fuel plants in the grid are relatively inefficient open-cycle gas turbines (as opposed to more efficient closed cycle gas turbines);
(f) The carbon dioxide intensity emitted from the fossil fuels used in the grid;
(g) The degree of variability of wind resources over a period of time, and a host of others.
(h) Funding sources for some literature is sometimes from proponents or opponents of the energy source;
(i) Some of the literature is not peer reviewed, posing potential problems in quality control."

For simplicity, let's assume the average CO_2 emissions intensity of Australia's electricity generation is 1 tonne per MWh (The figure varies by state and by year)[2].

From Inhaber's chart, at 1% wind energy penetration, emissions are reduced by 90% per MWh of wind generation. This equates to a reduction of 0.9 tonne per MWh of wind energy. However, at 20% wind energy penetration the CO_2 reduction is just 3.6%, or 0.036 tonne per MWh of wind energy.

CO_2 Avoidance Cost

For wind power to be viable the price for electricity would need to be about $120/MWh. The current average wholesale price of electricity is about $30/MWh[3]. So wind energy must be subsidised by about $90/MWh. If we have a carbon price of $25/MWh then the Renewable Energy Certificates (RECs) need to reach $65/MWh to make wind viable. (That means the consumer must subsidise wind by $90/MWh, or three times the current wholesale price of electricity.). The figures are summarised in Table 1.

Table 1:

Electricity price	$/MWh
Needed for wind power to be viable	$120
Current average wholesale electricity price	$30
Carbon price (assumed)	$25
Electricity price, including carbon price	$55
Renewable Energy Certificate (REC) price needed	$65
Total subsidy needed	$90

Let's calculate the cost of emissions avoided by wind generation at 1% and 20% wind energy penetration.

From Inhaber's chart, at 1% wind energy penetration, CO_2 reduction is 90%. Using the emissions intensity for electricity of 1 t/MWh this equates to 0.9 tonnes per MWh. Wind energy costs $90/MWh more than the current average cost of electricity. This is the cost we must pay to avoid CO_2 emissions with wind energy. At 1% wind energy penetration, the cost per tonne CO_2 avoided is:

$90/MWh / 0.9 t/MWh = $100/t CO_2 avoided.

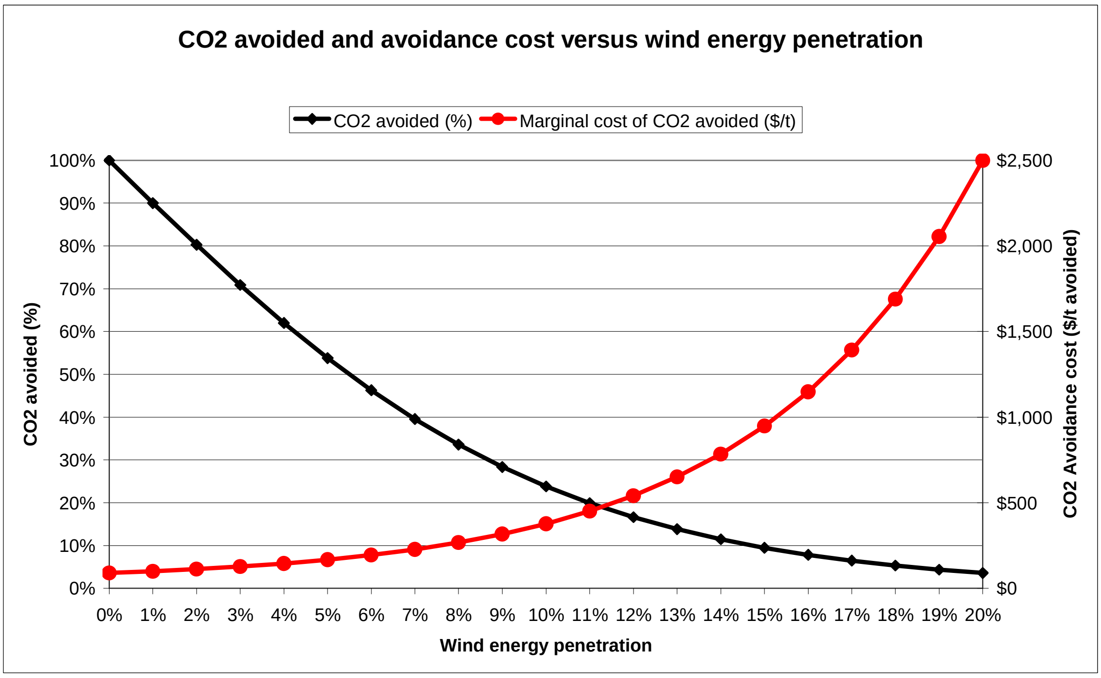
At 20% wind energy penetration the cost per tonne CO_2 avoided is:

$90/MWh / 0.036 t/MWh = $2,500/t CO_2 avoided.

These figures are for the cost to avoid an additional tonne of CO2 by increasing wind penetration.

Figure 2 shows the CO_2 avoided and the cost of avoidance versus wind energy penetration.

Figure 2:



Sensitivity Analysis

The CO_2 avoidance cost is sensitive to the wholesale electricity price and to the minimum price needed for wind power to be a viable investment. Figure 3 shows the results for six scenarios. The inputs for the six scenarios are listed in Table 2:

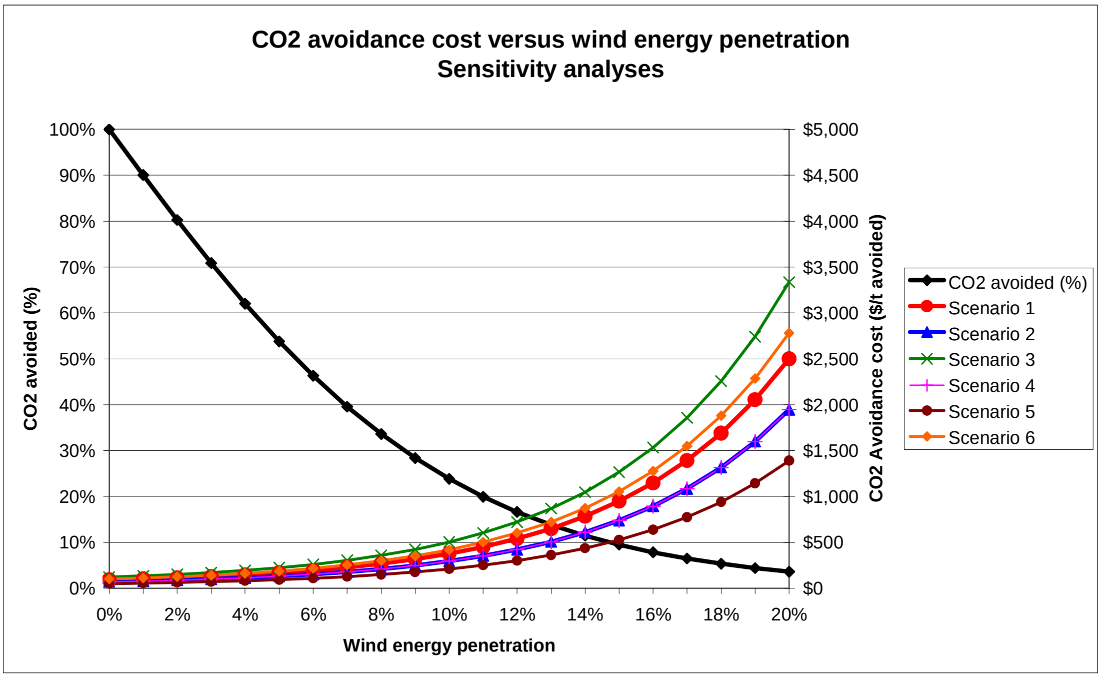
Table 2:

Scenario	Average wholesale electricity price ($/MWh)	Electricity price for wind power to be viable ($/MWh)	Notes
1	$30	$120	1, 3
2	$30	$100	1, 4
3	$30	$150	1, 5
4	$50	$120	2, 3
5	$50	$100	2, 4
6	$50	$150	2, 5

Notes:

1. 30/MWh quoted in Reference 3
2. $45.4/MWh Wholesale Price of electricity, 2008-09, ABARES (2011)[4]
3. $120/MWh quoted in Reference 3
4. $100/MWh low end of the minimum price commonly quoted for wind power to be viable
5. $150/MWh median value for new entrant wind generation from EPRI (2010)[5]

Figure 3:



The greatest uncertainty is the Inhaber equation. As Inhaber states "*There are considerable uncertainties in developing a curve of this type.*" However, to conduct meaningful sensitivity analyses on the range of possible values for the Inhaber equation is beyond the scope of this simple analysis. Inhaber's paper does not include ranges for the constants in the equation.

Carbon Price Implications

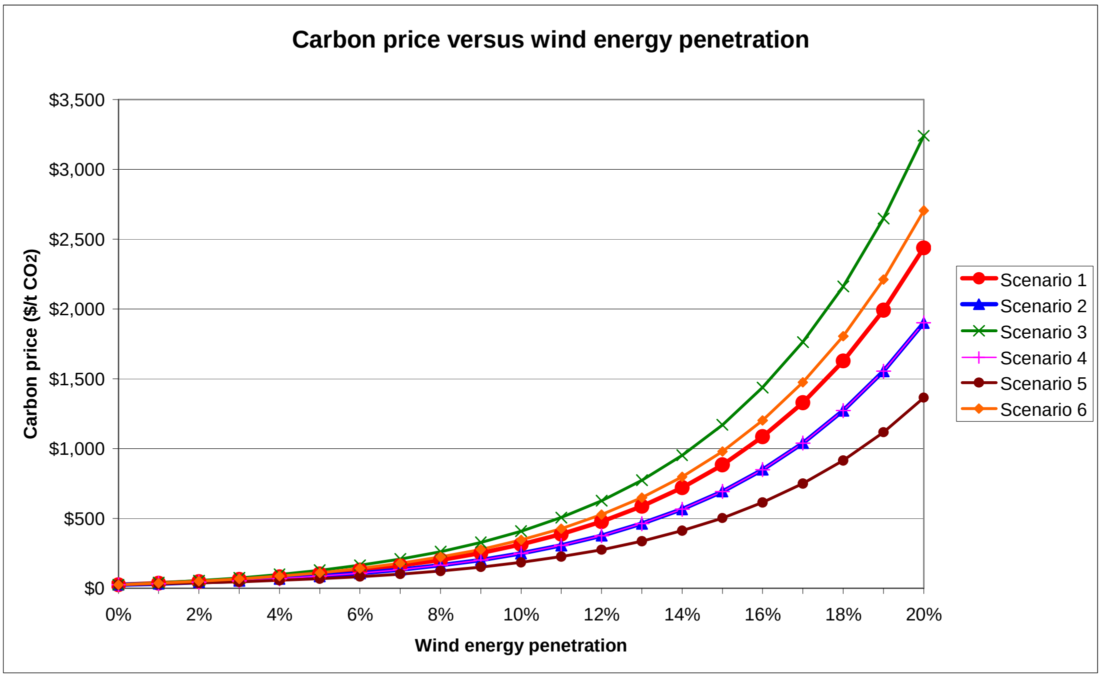
A carbon price of $2,435 per tonne CO_2 would be required for wind power to be viable at 20% penetration. This is for Scenario 1. The carbon price required for the six scenarios is plotted in Figure 4.

A carbon price of $2,435 per tonne is one hundred times the expected initial carbon price of about $25 per tonne CO_2. This indicates how much the carbon price would need to increase to make wind power reach 20% penetration based on carbon price with an REC price about double what it is now. The Australian Renewable Energy Target is 20% renewables by 2020 and most of this is expected to be provided by wind power. The carbon price would have to increase by a factor of nearly one hundred above the likely initial carbon price to achieve the target.

For the carbon price to stay below $100/tonne CO2, wind energy penetration would have to be less than about 5% and the Renewable Energy Certificates price above $65 (for Scenario 1).

Another issue is that the carbon price will be paid by the back-up generator owners not the wind farm owners. This is clearly unreasonable since wind is contributing to reduced efficiency of the back-up plant.

Figure 4:



Conclusions

As wind energy penetration increases from 1% to 20% the CO_2 avoidance cost increases from $100 to $2,500 per tonne.

The quantities and costs calculated are sensitive to the input assumptions and input data but the broad conclusions are robust to the range of input values tested.

Considerable uncertainties apply to the inputs for the Inhaber equation upon which this analysis is based and therefore to the results. However, these uncertainties have not been quantified.

A carbon price of around $2,500 per tonne would be needed for wind power to reach 20% penetration. The Renewable Energy Target is 20% renewables by 2020 and most of this is expected to be provided by wind power. Therefore, the expected initial carbon price of about $25 per tonne would have to increase by a factor of one hundred to achieve the Renewable Energy Target.

For the carbon price to be below $100 per tonne wind energy penetration would have to be less than about 5% (and Renewable Energy Certificates price above $65 per tonne).

Wind energy is a high cost way to avoid CO2 emissions.

Australia is paying a high price for policies that mandate renewable energy while at the same time prohibiting other low emissions electricity generation options.

References

[1] Herbert Inhaber (2011). *Why wind power does not deliver the expected emissions reductions*. Renewable and Sustainable Energy Reviews 15 (2011) 2557–2562 http://www.sciencedirect.com/science/journal/13640321

[2] Department of Climate Change and Energy Efficiency (2010. *National Greenhouse Account (NGA) Factors*, Table 5. http://www.climatechange.gov.au/~/media/publications/greenhouse-acctg/national-greenhouse-factors-july-2010-pdf.pdf

[3] Matt Chambers, "*Force of the near future*", article in "The Renewable Energy Special Report", *The Australian*, 16 May 2011; figures attributed to Tim Nielsen, head of economic policy at AGL.

[4] ABARES (2011). *Energy in Australia 2011*. p22 http://adl.brs.gov.au/data/warehouse/pe_abares99001789/Energy_in_Aust_2011_13e.pdf

[5] EPRI (2010). *Australian electricity generation technology costs, - Reference Case 2010.* Table 10-9 to Table 10-11, p10-4 http://www.ret.gov.au/energy/Documents/AEGTC%202010.pdf