PREAMBLE

Under Australia's Renewable Energy Target (RET) scheme wind and solar power generation are set to provide an increase in the supply of electricity over the next decade. The target is for 20% of electricity consumed to be from renewable energy by 2020 but this seems likely to be exceeded. Because wind and solar are extremely variable in output, efficient use of these technologies relies on the grid being supplied by gas-turbine generators as back-up. Together the renewable and gas-turbine generators constitute a pseudo base-load generator ensuring a constant and predictable supply to the system. Because over 20% of the generating capacity is set to come from this system it is important to analyse where this expenditure in new base-load capacity is taking us in terms of greenhouse gas saving and cost of generation which will ultimately be paid by the consumer. In the first of three papers I address the question of whether or not wind/gas- turbine generators save any greenhouse emissions relative to gas driven combined cycle generation, in the second paper I discuss the cost of wind/gas-turbine generation in a period of rising gas price and in the third I discuss the absolute greenhouse savings relative to established coal-fired generators.

PAPER 1

DO WIND-FARMS/GAS-TURBINES SAVE CARBON?

Abstract

Do wind farms save carbon dioxide emissions? The answer seems obvious that they do. However, as wind farms have spread, there has been a concomitant development of gas based power plants with the duty to supply power in times when the wind farm cannot generate because of low, or too high, wind speed. Thus a constant supply of power is supplied to the network without the necessity to manage the varying levels of generation provided by the wind farms. In effect the wind farms and the gas based power generators together form a base-load generation system, even though both gas turbine and wind-farm may be geographically separate [1]. Although the wind-farm operation would save carbon emissions, the balancing gas generator is a significant emitter.

Furthermore, the gas generators are all open-cycle gas-turbines of low efficiency. The question posed is if these gas units were replaced with the more efficient combined-cycle operations and the associated wind-farm decommissioned would carbon savings result? The answer is that it depends on the efficiency of the wind-farm and on the evidence to-date at least half of the existing wind-farm operations could be decommissioned with benefits to carbon emissions provided the complementary gas plants are upgraded to combined cycle operations.

Background

Today Australia has nominal wind-farm capacity of over 3GW. Operational output of individual wind-farms ranges from zero to the nominal capacity depending on the wind speed. Rating of individual turbines are for an optimum range of wind speeds and when wind falls below or above the optimum range less power is generated. Over a year, the average output of a typical wind farm is only about

[1] G. King (Origin Energy), Interview with Alan Kohler ABC "Inside Business" 21 July 2013

22 to 42% of the nominal capacity. Because the output is dependent on the vagaries of the wind, the variable out puts places enormous strains on the distribution network which has somehow to balance the varying loads.

This balancing act is performed by open-cycle gas-turbine generators which have grown in number and capacity along with wind-farm developments. Open-cycle gas-turbines are not very efficient (typically 35% efficiency) but perform the duty because they can be ramped at very high rates, typically over 20% per minute[2]. This level of ramping is not achieved by other generator systems which are typically in the 2% per minute range.

Converting the open-cycle gas-turbines to combined cycle operations by raising steam from the hot turbine exhaust considerably improves efficiency (to about 50 to 55%), that is more power is generated from the same quantum of gas and associated carbon emissions. The downside is that the more efficient plant will not perform the duty of balancing the wind-farm generators in the system without resort to actions such as dumping (wasting) the co-generated steam so as to drop the generator output.

The introduction of wind and solar to the generating network has resulted in the boom for gas-turbine generation. The question posed is if these where to be converted to combined cycle, and the complementary renewable generator closed, would this result in lower carbon emissions? This is what we attempt to address.

Wind-Farms

Table 1 lists current and pending wind-farm developments[3]. Wind-farms are in every state with total nominal capacity in excess of 3GW.

The actual output relative to the capacity is estimated in the final column from various sources. Generally, and for obvious reasons, wind turbine manufacturers quote high typical generation factors based on the optimum operation of their turbine. Proponents and owners of wind-farms generally quote lower values than the manufacturers but are generally several percent higher than actual output measured independently. The average from the available independent data is about 33%. This is relatively high compared to other data from the UK[4] which typically gives factors of 25% for land base wind-farms.

Vestas Wind Systems AS has published life cycle analyses for its products[5]. These detail typical optimum operation and claim efficiency factors over 40% with wind speeds in the range of 9.5m/s at 80m height from a 3MW turbine. The Global Warming Potential (GWP) is given as 6.2g CO2e per kWh for the 90MW turbine operating for 20 years.

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[2] Black & Veatch, "Cost and Performance Data for Power Generation Technologies", National Renewable Energy Laboratory, February 2012

[3] Data and capacity factors are taken from W, Forster, Energy Generation, Jan-Mar 2013, p. 20 and http://windfarmperformance.info/ or proponent website

[4] UK Department of Energy and Climate Change, National Renewable Energy Statistics: https://restats.decc.gov.uk/cms/load-factors/

[5] For Example, P. Garrett and K. Ronde "Life Cycle Assessment of Electricity Production from an onshore V90-3.0MW Wind Plant," September 2012, Vestas Wind Systems A/S, Aarhus, Denmark

Table 1: Existing and propose wind-farms in Australia

STATE	NAME	OWNER	CAPACITY (MW)	FACTOR
NSW	CAPITAL	INFIGEN	140.7	26%
NSW	WOODLAWN	INFIGEN	48.3	
NSW	CULLEREN	ORIGIN	30	35%
NSW	GUNNING	ACCIONA	46.5	
NSW	CROOKWELL	ERARING ENERGY	4.8	
NSW	BLANEY	PACIFIC POWER	9.9	
NSW	HAMPTON	PRIVATE	1.32	
NSW	KOORAGANG		0.6	
SA	CANUNDA	GDF SUEZ	46	30%
SA	CATHEDRAL ROCKS	ACCIONA	66	33%
SA	CLEMENTS GAP	PACIFIC HYDRO	58	35.30%
SA	COOPER PEDY		0.15	
SA	HALLET 1	AGL ENERGY	94.5	39.10%
	HALLET 2	AGL ENERGY	71.4	39.20%
	HALLET 3	AGL ENERGY		
	HALLET 4	AGL ENERGY	132	
	HALLET 5	AGL ENERGY		
SA	LAKE BONNEY 1	INFIGEN	80.5	26%
	LAKE BONNEY 2	INFIGEN	159	25%
	LAKE BONNEY 3	INFIGEN	39	22.80%
SA	MOUNT MILLAR	MERIDIAN ENERGY	70	29%
SA	SNOWTOWN		170	41.90%
SA	STARFISH HILL	TRANSFIELD?	34.5	26.30%
SA	WATERLOO	ROARING 40s	111	26.40%
SA	WATTLE POINT	AGL ENERGY	90.75	33.60%
TAS	HUXLEY HILL	HYDRO TASMANIA		
TAS	MUSSELROE	HYDRO TASMANIA	168	
TAS	WOOLNORTH	GUOHUA/HYDRO TAS	65	38.70%
	WOOLNORTH	GUOHUA/HYDRO TAS	75	38.70%
VIC	CODRINGTON	PACIFIC HYDRO	18.2	
VIC	TOORA	TRANSFIELD?	21	39%
VIC	CHALLICUM HILLS	PACIFIC HYDRO	52.5	28%
VIC	WAUBRA	ACCIONA	192	39%
VIC	WONTHAGGI	WIND POWER P/L	12	
VIC	CAPE BRIDGEWATER	PACIFIC HYDRO	58	35.70%
VIC	CAPE NELSON	PACIFIC HYDRO	44	35.70%
VIC	YAMBUK	PACIFIC HYDRO	30	32.80%
VIC	HEPBURN	HEPBURN WIND	4.1	
VIC	BALD HILLS	WIND POWER P/L	104	
VIC	MACARTHUR	AGL/MERIDIAN	420	
VIC	MORTONS LANE		30	
VIC	OAKLANDS HILL	AGL ENERGY	67.2	
WA	ALINTA	INFIGEN	89.1	
WA	ALBANY	VERVE ENERGY	35.4	
WA	EMU DOWNS	STANWELL	79.2	
WA	NINE MILE BEACH		3.6	
WA	TEN MILE LAGOON		2.03	
WA	MURIMBIDA	VERVE ENERGY	55	
WA	COLLGAR	USB	206	
TOTAL/AVE			3336.25	32.88%

Gas Generation

There is in excess of 5GW of open cycle gas turbine generation in eastern Australia alone. The US National Renewable Energy Laboratory (NREL) has issued a Life-Cycle Analysis (LCA) for a gas turbine combined cycle plant[6]. This comprehensive report has been used to disaggregate the gas-turbine cycle from the steam-cycle of the combined cycle system. The materials of construction are detailed in the report. Data abstracted from the report is shown in Table 2.

[6] P. L. Spath and M. K. Mann, "Life Cycle Assessment of a Natural Gas Combined Cycle Power generation System," NREL/TP-570-27715

The facility has a total nominal capacity of 505MW, 337MW in the gas-turbine generator and the rest in the steam generator. The GWP for the combined cycle facility of 499gCO2/kWh (tCO2e/GWh). This is dominated by fuel considerations with construction and decommissioning and NOx abatement by ammonia injection being almost insignificant. Although, a considerable portion of the GWP is assigned to gas production and distribution, the principal source of carbon emissions is the fuel.

For this analysis GWP of emissions from gas production and distribution are irrelevant to the debate, because in this paper since we are essentially comparing a wind-farm – gas-turbine system with a gas-turbine combined-cycle generator both using the same quantum of gas. Gas emission at source is important in a life-cycle analysis and issues relating to this will be addressed in a subsequent paper but are ignored here.

The gas usage in the facility is stated to be 1673t/d of gas with a higher heating value of 53.5GJ/t (MJ/kg). Making the assumption that this is methane gives an estimated GWP of 379.6tCO2e/GW compared to the NREL quoted vale of 372.2tCO2e/GW.

Table 2: Data for GWP (gCO2e/kWh) of natural gas combined-cycle plant

	gCO2e/kWh	
Power Plant	372.2	74.60%
Gas production and distribution	124.5	24.90%
Construction and decommissioning	2	0.40%
Ammonia (for Nox control)	0.4	0.10%
TOTAL	499.1	100%
Facility		
Output	MW	505
gas turbines	MW	337
Steam turbines	MW	168
Gas feed rate	t/d	1673
Efficiency (HHV)	%	48.80%
Operating factor	%	80%
Gas (HHV)	GJ/t	53.46
Gas feed rate	t/d	1673

The GWP for the combined cycle plant can be used to estimate the GWP of the gas turbine system alone by assuming that from the same quantum of gas (1673t/d) only 337MW can be generated rather than the 505MW of the combined cycle; with the assumption that the steam cycle involves no carbon emissions except that for the construction materials which are insidnificant. If we ignore this minor contribution then the GWP of the gas turbine is estimated at 568.8tCO2e/GW (=505/337x379.6).

Wind-Gas Generation

For this work it is assumed that emissions from the materials of construction are similar (on a MW to MW basis) as the Wind-Farm data. This gives a higher value than the NREL work but is very small compared to the carbon emissions from the fuel.

The data for the wind-farm and gas options are shown in Table 3. This assumes a hypothetical wind-farm of 100MW with an efficiency factor of 33% so that on average it will generate 33MW annually.

To supply the grid with 100MW, 67MW is required by a gas-turbine generator somewhere in the system. The result is that the constant 100MW is delivered at a total of 339205t/y of CO2e.

By contrast a natural gas combined cycle plant generating 100MW (125MW facility with 80% load factor) will emit 343216tCO2e per year – a nominal carbon saving of only 4000t of carbon dioxide emissions.

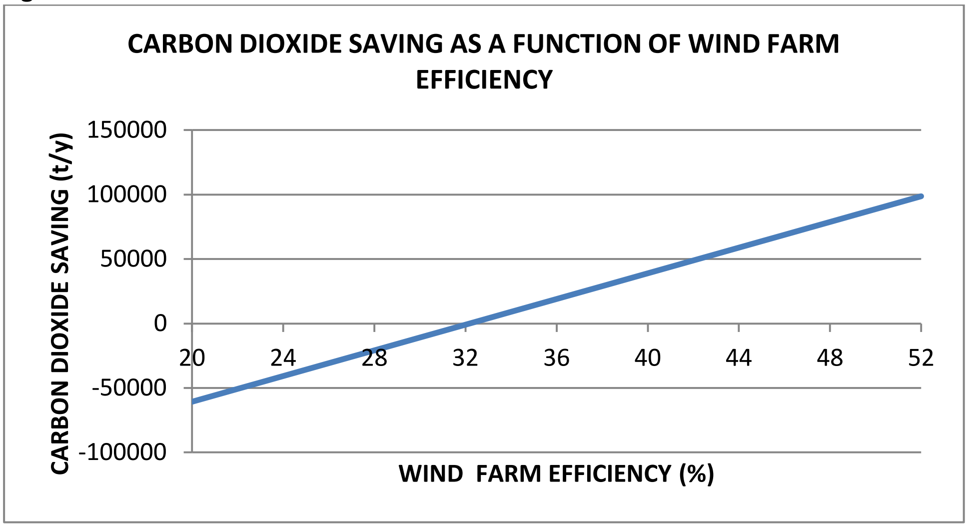
Table 3: Wind-Gas Generator Statistics

HYPOTHETICAL WIND FARM		
OUTPUT	MW	100
EFFICIENCY	%	33.0%
ACTUAL	MW	33
OUTPUT	GWh/y	289.08
GWP	t/GWh	6.1
CO2	t/y	1763.4
GT BACKUP		
POWER	MW	67
	GWh/y	586.92
FACILITY GWP	t/GWh	6.1
GWP OPERATING	t/GWh	568.8
GWP TOTAL	t/GWh	574.9
CO2	t/y	337441.8
TOTAL		
CAPACITY	MW	100
	GWh/y	876
GWP	t/GWh	581.0
CO2	t/y	339205.1
CCGT		
LOAD FACTOR	%	80%
CAPCITY	MW	125
ACTUAL	MW	100
	GWh/y	876
GWP	tCO2e/GWh	379.6
FACILITY GWP	tCO2e/GWh	12.2
TOTAL GWP	tCO2e/GWh	391.8
CO2	t/y	343216.7
CO2 SAVING	**t/y**	**4011.5**

Sensitivity to Wind Farm Efficiency

Data in Table 1 indicates there is a wide range of recorded efficiencies for wind-farm operations – 22% to 42% with the average about 33%. The sensitivity of the carbon saving to this factor is illustrated in Figure 1.

Figure 1



The graph illustrates that on these calculations wind farm-gas-turbine combinations with efficiencies below 32% do not save carbon emissions relative to a gas-turbine combined cycle operation. Only combinations with wind-farm efficiencies higher than 32% yield savings.

Policy Implications

The construction of wind farms is being driven by the Renewable Energy Target scheme which aims to obtain 20% of renewable energy in the system by 2020. This is an attempt to reduce the carbon emissions by electricity generation. As can be seen in Figure 1, in effect this is only achievable with wind farm efficiencies higher than about 32%. Wind-farms operating below this figure fail to achieve this relative to a combined cycle generation using gas.

Carbon savings could be achieved if low efficiency wind-farms where decommissioned and the complementary gas-turbine upgraded to combined cycle. Solar power generally has much lower efficiencies, so it is expected that similar results would apply to solar generated power.

It is not clear if this would be acceptable or achievable because of the competing interests in the sector. One of the problems is that wind-farms and the complementary generators have different ownership structures. We do not have a command economy and no longer a state monopoly generating sector. Policy would require an incentive for one group of owners to decommission whilst another ownership group with an incentive to invest.

Furthermore, the argument presented here is irrelevant to many supporters of wind-farms. It is the RET that is the main game and efficiency considerations have no role. The complementary gas generation to make the grid work is seen merely as transitional to a totally renewable future.

Although this piece may be of academic interest, the generating cost implications are profound. This subject is addressed in the subsequent paper.

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