Kevin Casey
0418398616
kevincasey70@gmail.com
30-01-2012

Simulation of the ZCA2020 Solar and Wind Energy Integration

1) Introduction.

The purpose of this paper is to revisit the calculation of the integrating of solar and wind energies in the year 2020, as is presented in Part 3 of the ZCA Stationary Energy Plan.

2) The Data. ---

For Solar Data---The Australian Bureau of Meteorology, (BOM), provides satellite derived data of the solar energy arriving at locations in Australia as the ½hourly solar direct normal irradiance (DNI) in Mega joules per Sq metre, Mj/M^2 (or divided by 3.66 as KWh/m^2), for locations on a gridded system which has a resolution of 0.05 Degrees of latitude and longitude, as CSV files. For this study, the data for the whole of 2009 for the 12 sites used in the ZCA plan was taken and converted into Excel files for entry into the simulation.
For Wind Data---The Australian Energy Marketing Organisation (AEMO) makes available, on line, the monthly electricity generated in MW by all working wind sites in Australia, on their web site, http://windfarmperformance.info. The data for 2009, is made available in five minute intervals and Excel file format, and has been converted to ½hourly intervals for entry into the simulation.

For the Electricity Demand ----AEMO make available data on web page http://www.aemo.com.au/planning/0410-0013.pdf, which has been used to calculate the demand in half hourly intervals for all of 2009.

As the ZCA Plan is the study the year 2020, when Australia's electricity demand is estimated to be 325TWh per year, the entire data sets above must be scaled up from the demand of 220TWh per year in 2009 by multiplying it by a factor of 1.477 to reach the 325TWh figure for 2020.

.

The layout used for data collection and conversion is shown in Fig1.

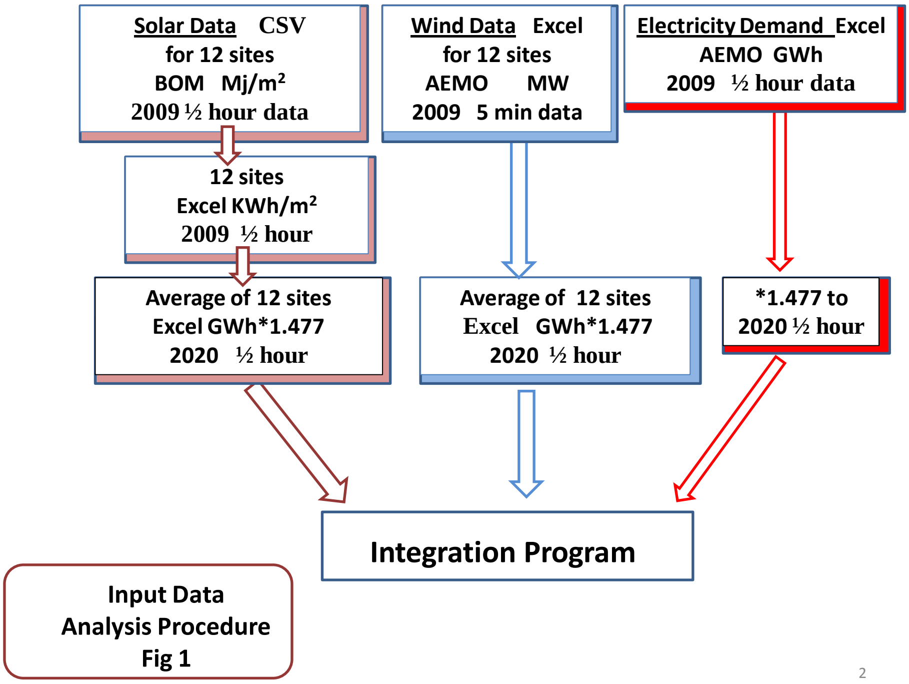


Fig 1

2

<u>3 Solar Data.</u> The following diagrams show some interesting and expected characteristics of the seasonal variation of the monthly irradiance over three years. Note in Fig 2, the value of insolation for the year 2010 shows consistently lower levels than the proceeding years. No explanation for this is has been found, despite an extensive web search.

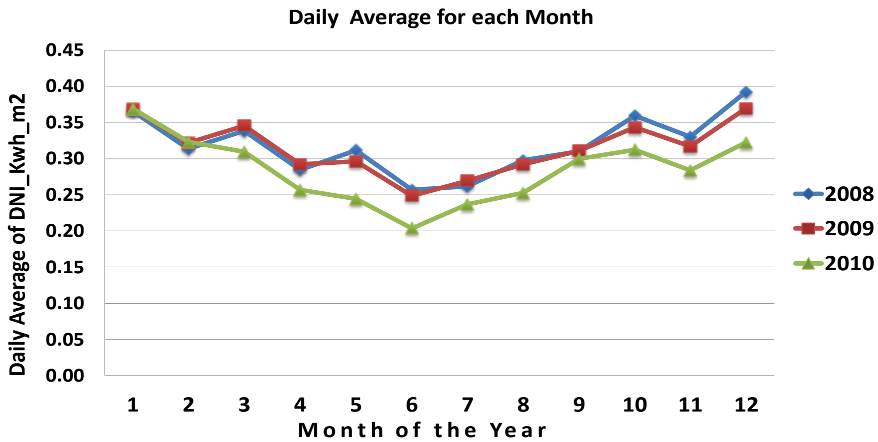
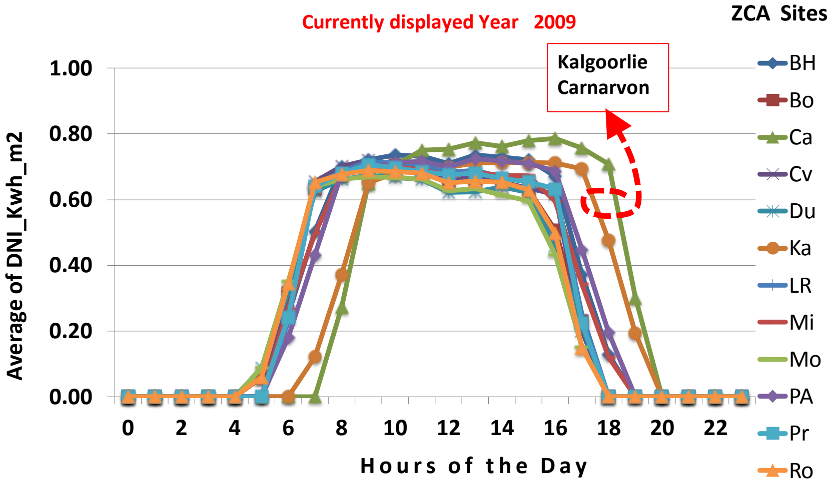


Fig 2

Variation of Solar Energy Insolation

5

Figure 3 gives a clear picture of contribution from each station at hours of the day expressed against Eastern Standard Time. Averages are quite aligned on the Eastern State sites, while the Western State sites, after supplying their own needs, clearly shows a capacity to be able to make a considerable contribution to the Eastern States' evening peak demand, provided, of course that a low loss East-West transmission facility were established.



Average of DNI_Kwh_m2 Insolation versus hr of day (EST)

Fig 3

6

4) Solar Energy. From the BOM data, the solar irradiance at the twelve ZCA sites has been added to achieve the diagram of Fig 4, from which the figure of 7.29 Kwh per m^2 is derived as the average of these sites.

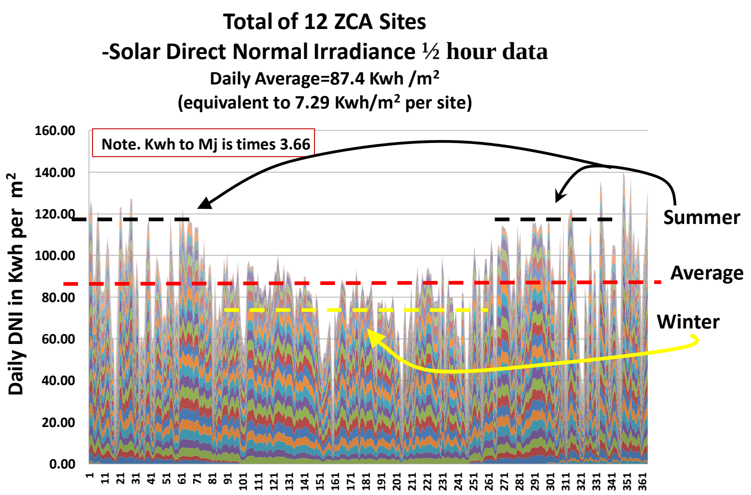


Fig 4

7

6) From Solar Energy to Electricity.

To determine the amount of electricity that can be generated from each site, the solar irradiance of Fig 4 is applied to the engineering characteristics of a commercial working Solar Thermal Plant.

The Sunlab 220 system that is already operational in Spain, and adopted in the ZCA Plan, has been used. The system has a 2.6 million m^2 mirror field, a central solar tower and a pair of tanks for molten salt storage for 17 hours full load capacity, and a steam turbine capable of delivering 220MW continuously. See reference 1. The manufacturer has designed it to deliver 1400GWh of electricity annually, and this figure has been adopted as a basis for the ZCA Plan.

Applying this methodology, firstly, the individual ½ hourly data figures for the 12 ZCA sites of Fig4 are divided by 12, to bring them to a one site average of the solar irradiation in Kw/m^2, which is then aligned to manufacturer's design commitment of 1400GWh per year. It therefore follows that the individual ½ hour values of irradiance and the electricity generated must also be relative to each other on an instantaneous basis. This relationship turns out to be a simple multiplication factor of 0.52, being the factor found necessary to align the average of the irradiance in KWh/m^2 to the output value of the manufacturer's design commitment in GWh.

While many profiles of the irradiance input may well cause the desired 1400GWh to be generated, it must also be true that the profile of the average of the 12 sites will certainly do it.

The result is shown in Fig 5.

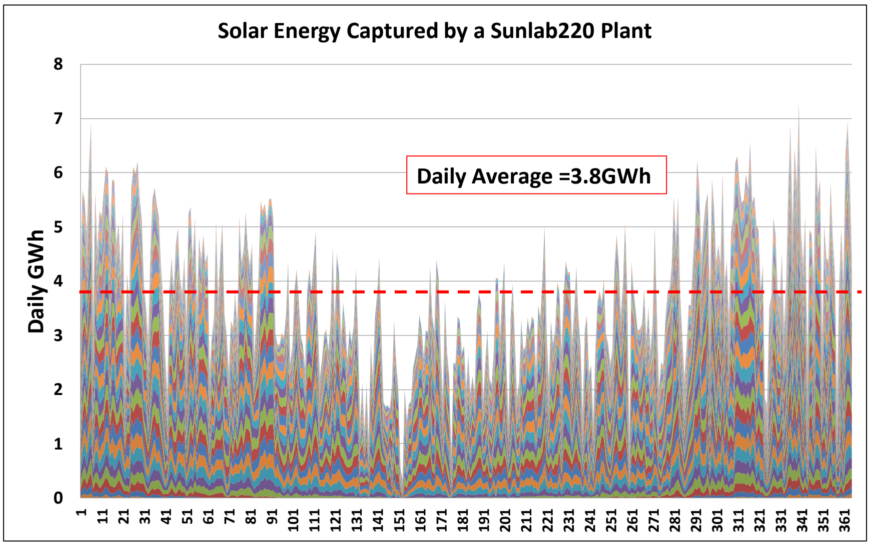


Fig 5

One Sunlab 220 in Australia

9

As a sideline, the table below shows the overall solar energy to electrical energy efficiency of a Sunlab220 system, not that such a figure matters greatly, it is just for interests' sake.

	m^2 mirrors	mj/m^2/d	mj/kwh	theoretical	GWh year	efficiency
			conversion	GWh day		%
theoretical	2600000	*22	/3.66/1000	=15628*365	=5704371	1388/5704371
claimed				3.8*365	=1388	**=2.4%**

7) Wind Energy

Wind data was obtained from the Australian Energy Marketing Organisations' web site, for every month of the last two years. See reference 3.

For September 2009 the instantaneous output level in MW for each 5 minute interval was downloaded and is shown in Fig 6. Down the right hand side of the graph is the name of each of the Wind Farms in service in Australia during that month, each shown with a distinctive colour, and these are accumulated in the graph to show the contribution of each farm to the total.

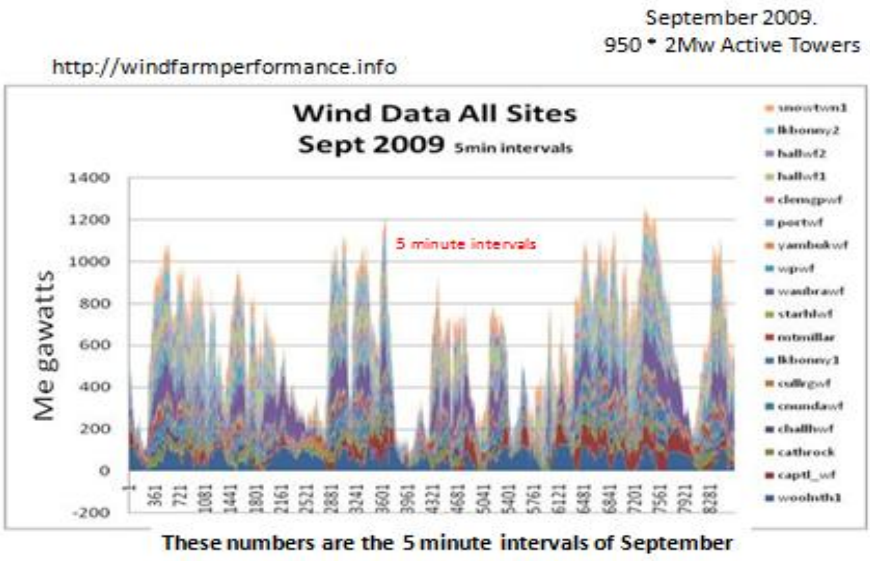


Fig 6

By adding such information for every month in 2009, and converting it to ½ hour data, the yearly output can be calculated for a single tower in an average location as is shown in Fig 7. With a Nameplate capacity of 2 *24=48MWh a day , and an actual generation of 11.7MWh a day , the Capacity Factor for this average turbine in all Australia for this year was 24.3%.This average is calculated from the in-service data of the 950 turbines installed at that time.

In the ZAC Plan it is stated that wind power never falls below 15% of the average value. Analysis of the 2009 figures shows a contrary result. The number of occasions during the year when the total output fell below 15% of the average were:- on 12 single day occasions during the year; on 3 double day occasions; on 1 triple day occasion; and on 1 quadruple day occasion. However the extra tank storage capacity required by the simulation calculation compensates for these gaps of input power.

As it can be presumed that the operators of these working turbines have selected more or less the locations with best possible performance, the additional turbines calculated to be installed as part of this study are assumed to perform to the same output.

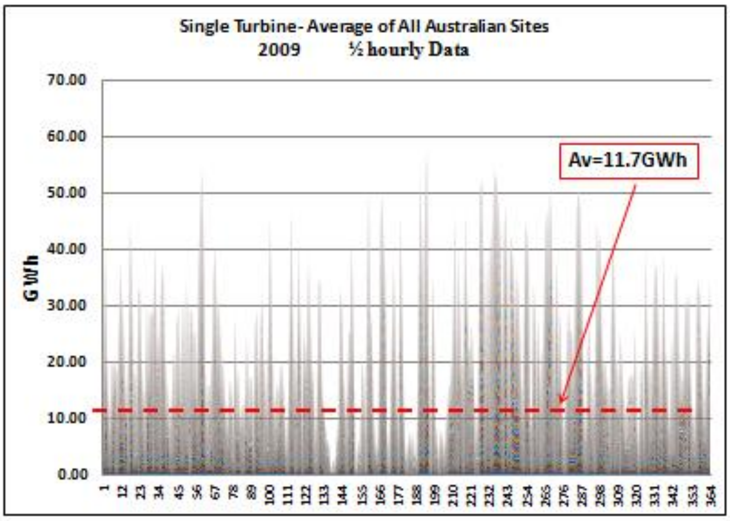


Fig7

As only 2MW turbines are installed in Australia, the data provided by AEMO is only for these systems. In order to be in line with the ZCA Plan where it is assumed only 7.5MW turbines will be employed, the simple conversion 2:7.5 is used when calculating between number of, and output from, turbines of these two sizes.

8) Demand. The demand for 2020 was derived by taking the 2009 figures and multiplying by 1.477.as shown in Fig 8.

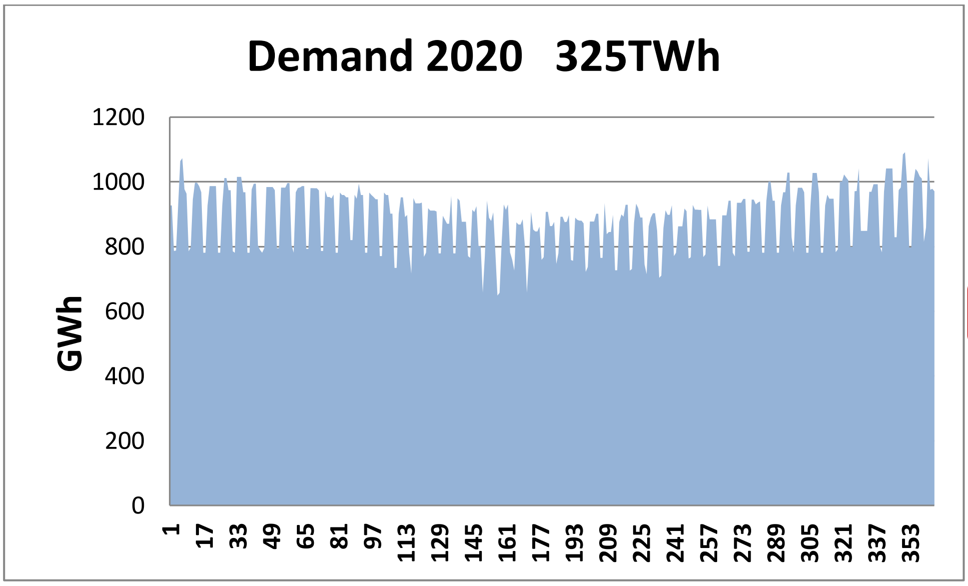


Fig 8

9) Integration Procedure.

With the demand, the solar and the wind energy data to hand, the integration simulation can proceed, following the logic laid out in Fig 9.

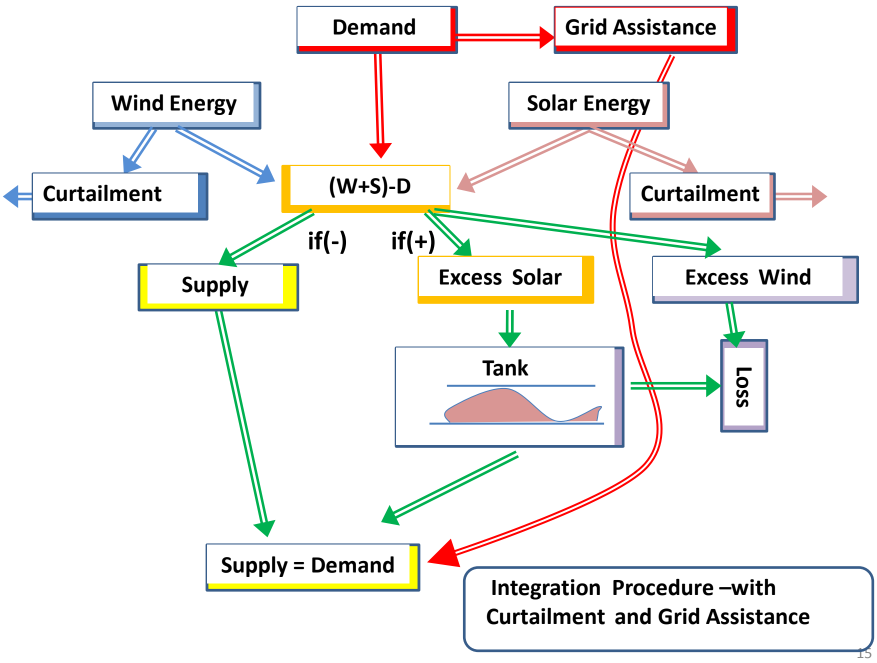


Fig 9

The energy that will ultimately be supplied from hydro/biomass is initially deducted from the demand, and added directly to the supply.
This is called Grid Assistance in Fig9.

For each half hour interval, the value of the solar, plus the wind, minus the demand energy is calculated. If the solar plus the wind is greater than the demand, that amount necessary to equal the demand is sent to the supply, and the excess solar energy is sent to the tank for storage. If the excess is in fact wind energy, it must be sent to loss, as wind energy cannot be added to heat the molten salt. If there is no excess, the total of the solar plus the wind energy is sent directly to the supply, with nothing available to go to the tank for storage in that half hour interval.

At each half hour interval, any shortfall of supply is taken from the tank, so that the demand is always met; provided of course that there is adequate energy in the storage tanks at that instance.
A loss of 1% of energy in the tank each day is taken from the tank as heat loss.

The goal is to adjust the amount of solar and wind energy generated by adjusting the number of solar units and wind turbines, together with using curtailment of the amount collected by each unit, so there is always enough energy stored in the tank to meet any potential shortfall in any half hour supply interval.

To reject unwanted wind energy during curtailment, the blades of some turbines are simply turned out of the wind, that is, the blades are feathered. To do this at solar plants, it is a matter of defocusing the mirrors, at some of the plants, so that their energy does not reach the central receiver. The unwanted energy is simply lost to the system, which reduces the overall capture efficiency and should be minimised.

In this way the tank is far more than a night time backup, but is a dynamic buffer acting to fill the gaps in the variable solar and wind inputs and thus providing a far smoother output profile to more accurately match the actual half hour demand. In a mechanical analogy the tank acts as a kind of shock absorber, or in electrical terms, a surge capacitor.

Two conditions apply---
1) that the tank cannot be allowed to have a negative value, (rather obvious).
2) That the amount of energy in the tank at the end of the year is equal to that at the beginning of the year, to guarantee continuity into succeeding years.

With wind it is operationally easier to execute curtailment at short notice, and this form of curtailment is employed in preference to solar curtailment in this simulation. At the same time the number of solar and wind units are kept to a minimum to reduce unnecessary energy loss due to instantaneous over supply.

These two steps are done manually in this simulation and require a good amount of time and patience. The program operates in an iterative process whereby the energy in the tank during each half hour interval is calculated as:-
-the resultant energy from the previous half hour,
- plus excess solar energy added during that half hour,
-less the energy taken from the tank to satisfy that half hours' supply shortfall. At the end of each day, only 99% of the energy value is carried forward to the next day to account for an assumed 1% heat loss from the tank per day.
Fig 10 demonstrates the mathematics.

DAY$_1$, Tank $_1$ =Tank$_0$ + (Se $_1$-D$_1$)________________________T_{47}+(Se_{48} –D_{48})

Day $_2$, Tank $_{49}$ =0.99Tank$_{48}$ + (Se$_{49}$-D$_{49}$)------T$_{95}$+(Se$_{96}$-D$_{96}$)

:

:

Day $_n$, Tank $_n$ =0.99Tank$_{n-1}$ + (Se $_n$-D $_n$) _________T$_{n+47}$+(Se$_{n+48}$-D$_{n+48}$)

:

:

Day $_{365}$, --T$_{365}$+(Se $_{365+48}$ –D$_{365+48}$)

Fig 10

Se=solar excess energy in that half hour
D=demand in that half hour.
T$_0$ = the manually set zero value of energy in the tank.

Tank Calculation

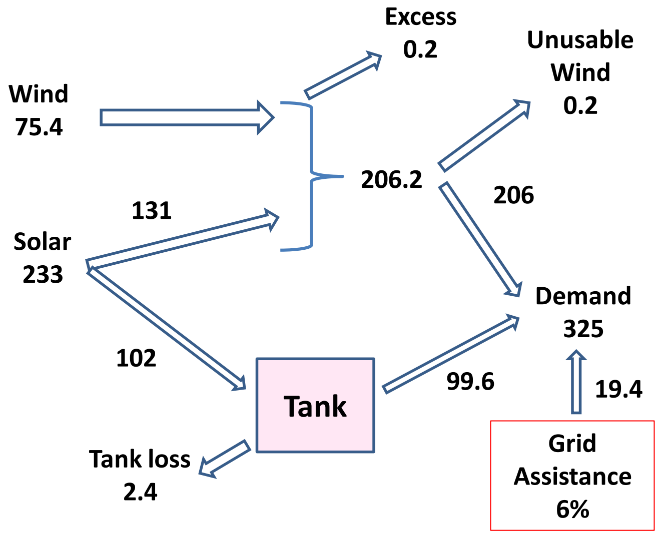
4

10) Result—

A configuration using 171 solar units generating 233TWh per year, and 19,750 wind turbines (2 MW) generating 75.4TWh per year together with 6% grid assistance of 19.4TWh per year was found to be necessary to match the demand of supplying the necessary 325TWhy.The energy flow for such an arrangement is shown in Fig11. The wind energy loss is minimal.
The thermal loss from the tank is a 2.4TWh per year.

The initial value of energy in the tank on day 1 was set at 900GWhe so as to equal the value on day 365.

The table at the side of this diagram is a copy of the "Control Panel" from the simulation program, showing all the controlling data for this run of the program.



Energy flow Diagram -6% Grid Assistance
325 Twhy Demand 2020
19,750 Wind Turbines & 171 Solar Units

Demand	304.8
Wind	75.4
Solar	232.9
W+S	308.26
Excess	0.16
Wind Loss	0.2
Solar to Tk	101.9
From TK	99.3
Tk Loss	2.5
Delta Tk	0.1
Supply	304.8
Grid Assist	19.34
GA%	6.0
Total	324.1
	Gwhe
Swing	1,500
T0 Gwhe	900
Tk/project	556
Tk/Unit	3.2
CO2 Red	93.7
n Wind	19750
m Solar	171
Curtailed	12.07
% (W+S)	3.95
Check sum	305.28
GWh/Tank Pr	2.7

16

Fig 11

Crucial to the ability of the configuration to supply 24hour power is that the tank, or more correctly, the capacity of each tank times the number of tanks per solar unit, is such as to be able to meet shortfalls in direct supply at any time.
The simulation program calculates the energy in storage at each ½ hour interval, and this is displayed in Fig 12. The maximum value is expressed as 1500GWhe, being the thermal energy equivalent capacity of the tanks to enable them to supply 1500GWh of electrical energy whenever required.
The energy level in the tank is not to have a value less than zero.
The tank pairs employed in the simulation and in the ZCA Plan have a storage capacity of 2.7GWhe each, and using this figure, together with the number of solar units (171) results in a requirement for 3.2 tanks pairs per solar unit to be able to meet the peak requirement of 1500GWhe.
This is at variance with the ZCA Plan where a single tank pair per unit is deployed.

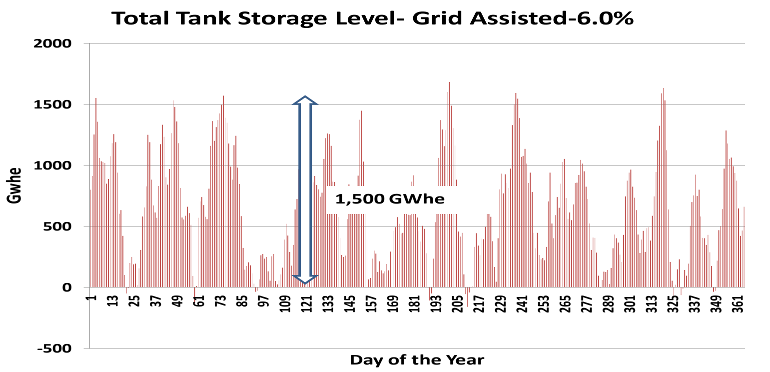


Fig12

17

The next two figures, Fig13 and Fig14 show the respective solar and wind usage as set by the program controls, and the resulting curtailed energy of each. The actual energy curtailed is a combination of the control setting for each ½ hour, multiplied by the instantaneous energy offering for curtailment at that instance.

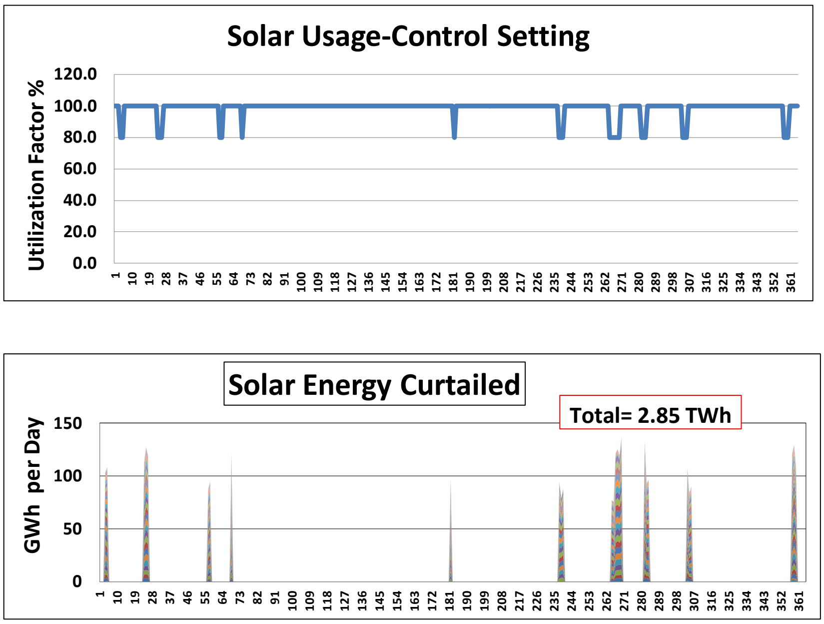


Fig13

21

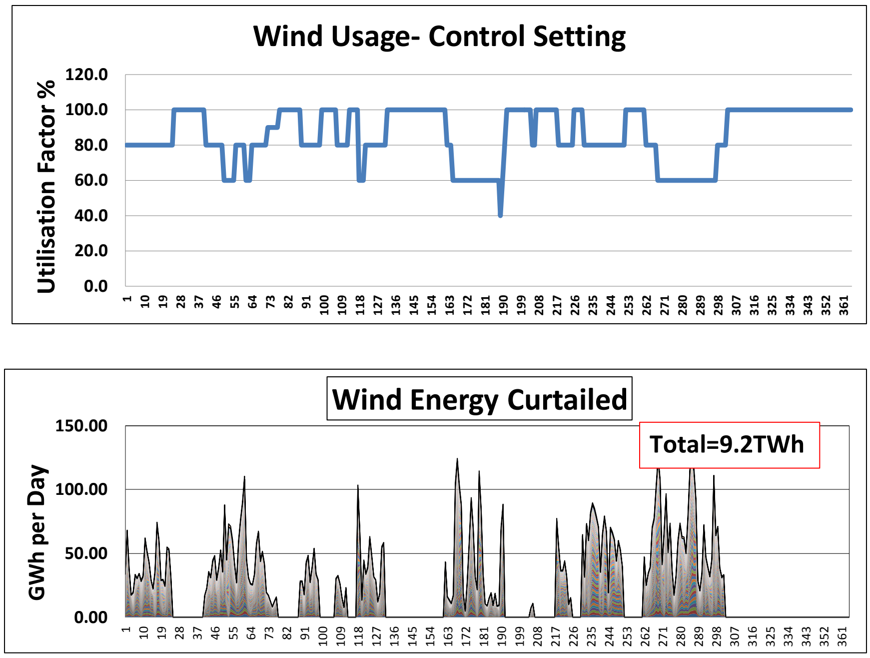


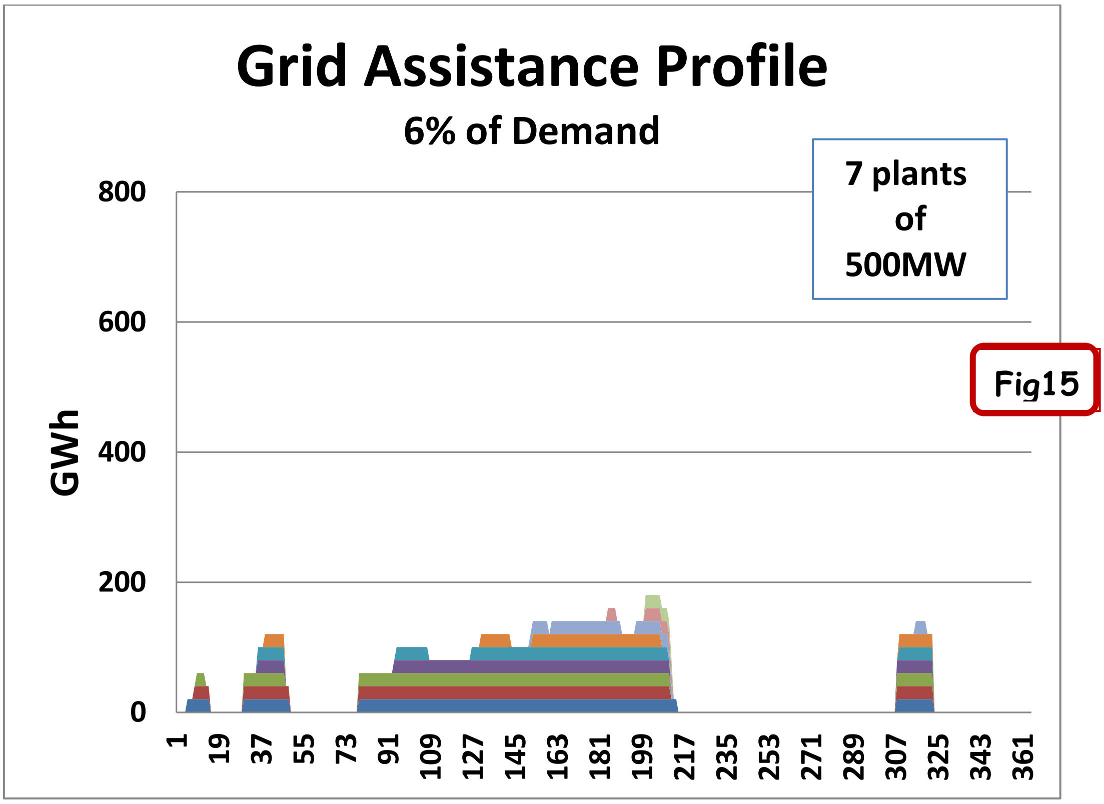
Fig14

22

It should not be thought that this is the unique solution; that is that this is the only combination that will satisfy the requirements. There are other combinations of the number of solar units and wind turbines coupled with different curtailment arrangements that would suffice. However all would be within a close range of the numbers used here, and some may require a slightly different number of tanks.
The simulation program unfortunately does not have an optimisation capability.

The demand for energy from the grid at the times when the solar plus wind sources prove inadequate is shown in Fig 15. Such back up from the grid can come from existing hydro, coal or gas plants, or the biomass plants as envisaged in the ZCA Plan. All these sources of energy are referred to as Grid Assistance in this paper.
The amount of grid assistance in the simulation has been adjusted to 6% to be approximately the same as the figure used for the ZCA Plan, 5.2%.
A reliance on hydro to be available at the time required and in the exact volume required is doubtful, in view of the conflicting interests of the Agricultural Community who require the scarce water resource to be available in the growing season, not when convenient for electricity generators.

The operating difficulty of having thermal plants meet a profile of this variability is not insignificant either.



Finally, in Fig16, the energy captured from each source is shown.

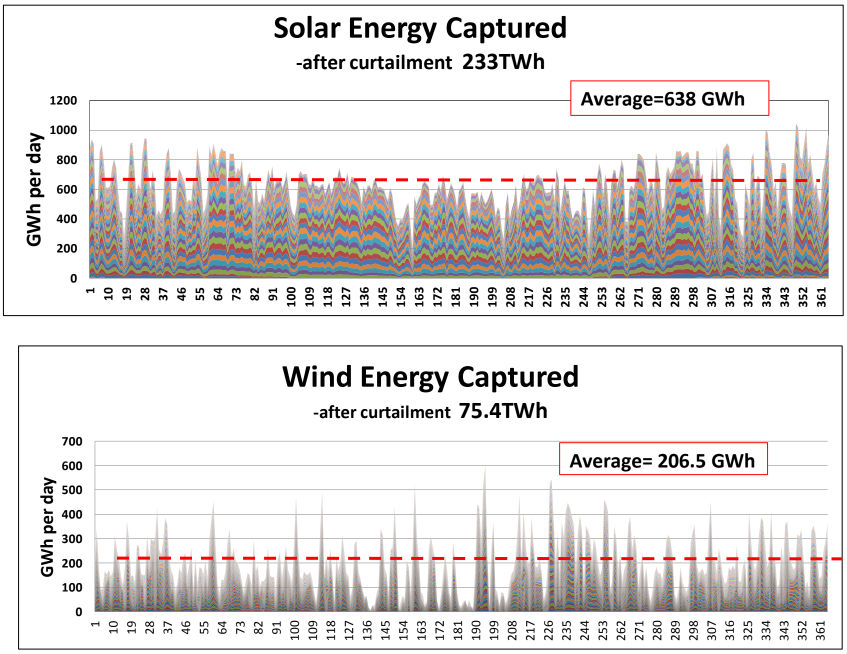


Fig16

20

The accuracy of the simulation can be checked by adding the derived profiles of solar energy sent directly to supply, plus the solar energy taken from the tank, plus the wind energy and plus the energy from the grid assistance to produce Fig 17.
The result in Fig 17 is identical, that is to within ½ %, of the original demand, as shown in Fig 8.
So the energy calculated for supply by the simulation is equal to the original demand !-A very pleasing result.

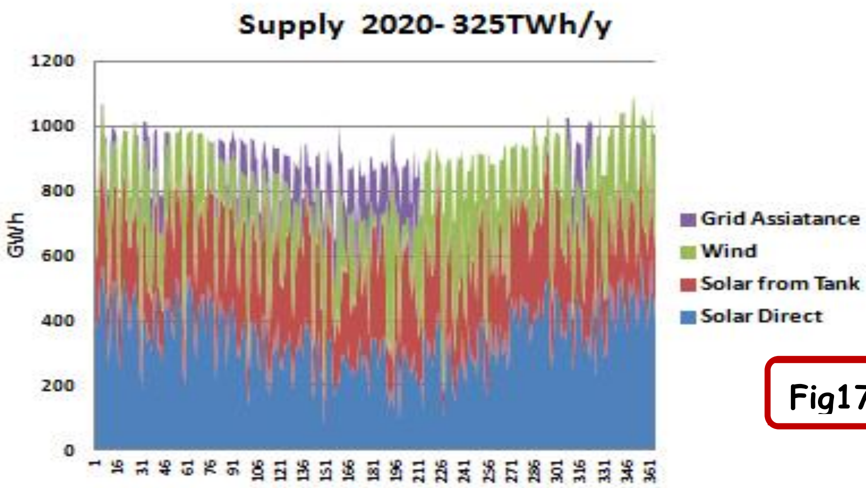


Fig17

17

11 Comparisons

The table below sets out the results of the simulation which achieves the same demand of 325TWh as does the ZCA Plan for 2020.

	ZCA2020 Plan TWh	Simulation TWh
Demand	308.1	304.8
Assistance	Biomass+ Hydro 5.2 % = 16.9	Grid 6% = 19.4
Solar Units	156	171
Solar Energy	216	233
Wind- 2MW --------7.5MW	24,000 6,400	19,750 5,266
Wind Energy	Not specified	75.4
Storage GWhe	419	1,500
Storage time	17 hours	1.8 days
Storage GWhe / tank	2.7	2.7
Tank pairs /Unit	1	3.2

Comparison

26

The simulation uses slightly more solar plants but fewer wind turbines than does the ZCA Plan, which results in a lower wastage of wind energy by the simulation.

The amount of assistance from the grid in the simulation is set to be equal (almost) to that of the ZCA Plan.

The significant difference shown by the simulation is that power cannot be supplied on a 24hour basis with Australia's variable solar and wind input, unless multiple tank pairs are employed.
To meet 2020 demand 3.2 tank pairs per Sunlab220 unit are required, giving 1.8 days of full power storage, in contrast to 17 hours in the ZCA Plan.

Taking the cost figures given in the ZCA Plan, and using a ratio of them as appropriate, an approximate cost comparison is provided below.

	Turbines 7.5MW	Cost	Solar Sites	Cost	Trans	Other	Total B$
ZCA2020 Plan With 5.2% hydro +biomass	**6,400**	**72**	**156**	**175**	**92**	**31**	**370**
Simulation Plus 6% Grid Assistance	**5,266**	**59**	**171**	**192***	**76**	**31**	**358**

* No allowance for extra tanks

Cost Comparison

26

Of incidental interest is the similarity between the capital cost per TWh, of the generating capacity of each technology. By combining costing figures with the energy generated as in Fig15, the following figures are calculated.
For solar thermal 0.82B$/TWh/y as against 0.78B$/TWh/y for wind, ignoring transmission costs.

12) Conclusion

Australia's electricity demand can be met by a combination of solar and wind energies, on a 24 hour basis using CSP with molten salt storage, and wind turbines.

Multiple storage tanks must be employed at each solar unit in order to achieve 24 hour continuity.