Scenario Analysis of Possible Sustainable Energy Futures for Alice Springs

J. Picton,[1] M.Watt[1] and I.MacGill[2]
[1]School of Photovoltaic and Renewable Energy Engineering
[2]Centre for Energy and Environmental Markets (CEEM)
University of New South Wales
Sydney 2052
AUSTRALIA
E-mail: j.picton@unsw.edu.au

Abstract

Global concern about the impacts of climate change and future energy security has sparked debate in Australia over the role renewable energy technologies could play in achieving a sustainable energy future. Availability, costs and intermittency issues have all been argued by some to limit renewable energy's possible future potential. Clearly these issues are largely context specific.

This paper presents the results of my undergraduate thesis: a scenario study exploring future options for renewable energy contribution to the Alice Springs electricity supply (Picton 2007). Wind energy, photovoltaics, solar thermal, municipal waste gas and energy storage options are modelled to illustrate their combined potential to contribute to Alice Springs' future electricity needs

The scenarios also explore the role of improved energy efficiency and fuel switching to facilitate renewable energy integration and sustainability outcomes. Past load data has been extrapolated for future growth to 2050 and has then been modified for demand side measures. Based on the modified load data, scenarios with varying renewable energy targets have been used to demonstrate potentially advantageous combinations of renewable technologies. Assumptions for CO_2 emissions and future renewable generation costs enable discussion of electricity prices and emission reduction potential.

Results suggest that increased electricity costs for renewable energy are compensated for by the low cost of energy efficiency, solar hot water and domestic gas. Advantageous combinations have been identified for low, medium and high levels of renewable generation. For low to medium levels intermittent generation performs best, where at higher penetration levels the increased cost for thermal storage becomes worthwhile. For 50% renewable generation a wind and solar combination shows significant advantages over using any one generation type alone. This reveals the resources compliment each other to meet this load shape.

1. INTRODUCTION

Recently, there has been significant concern over the environmental and economic impacts due to climate change in Australia and worldwide. Renewables hold great potential for emission reductions in the electricity sector; however the extent to which they can contribute to Australia’s energy future is debated. While renewable advocates argue that renewable technology is technically capable and affordable now, opponents argue that intermittency of generation and high costs will limit renewable energy contribution to our future. The recent announcement that Alice Springs has been selected as a 'solar city' means there is heightened interest in the potential for renewable generation in Alice.

This study aims to examine the renewable resource potential in Alice Springs. It is intended to provide a foundation for future studies, which may look at renewable energy policy strategies, or further explore promising renewable options. In order to achieve these outcomes, the study uses scenarios in the year 2050 with the aim of reducing emissions by 60% below 2005 levels. Demand side measures have been modeled to create a reduced 2050 electricity load for which economics and emission outcomes gauge advantageous renewable energy combinations. By examining different renewable energy targets, renewable generation technologies are discussed in terms of their most suitable penetration levels.

1.1. Background

Alice Springs is located at 23^o latitude, 133^o longitude and is home to a population of 24 000 (Alice Springs Town Council 2007).

The load profile for Alice Springs is predominantly residential (approximately 80%) with the remaining influence from the commercial sector; there are no significant industrial loads. Currently there are no off peak hot water tariffs. The current domestic electricity tariff is 15.1c/kWh with a 29.59c fixed daily charge. For the commercial sector the tariff is 17.46c/kWh with a 46.21c fixed daily charge (Power and Water 2006). Current electricity generation is supplied by a series of open cycle natural gas turbines and reciprocating engines which have a combined capacity of 67MW (Power and Water 2006).

The solar resource in Alice Springs is particularly good, with a yearly cumulative insolation of 11800[1] MJm^{-2} in 2005 (Bureau of Meteorology 2006). This good solar resource has been a driving factor for the large uptake of solar hot water. In 2001, 60% of Alice Springs households had solar hot water systems (CSAT 2005). Despite large uptake of solar hot water, there is still a significant residential hot water electricity load.

At Alice Springs airport in 2005 the yearly average wind speed at 10m was $3.8ms^{-1}$. Although this suggests a poor wind resource, Power and Water currently have a wind turbine installed at Epenarra and have proposed a wind – diesel system at Tennant Creek (Power and Water 2006). Inland areas of Europe have shown significant wind speed up at greater heights due to thermal effects; this might warrant interest in wind generation for inland Australia (Focken and Lange 2006). Data readings at greater heights are required to determine whether thermal speed up effects are significant for the wind resource in Alice.

2. METHOD

The modelling in Excel uses hourly load and weather data for the year 2005 to create possible 2050 generation and load profiles. Load data has been extrapolated with load growth to create a "business as usual" reference case. This reference case has then been modified to include energy efficiency, solar hot water and domestic natural gas. The remaining electricity load has been used to model renewable energy percentage contribution targets. The renewable combinations for the targets are optimised for cost and emission reduction.

For demand side measures and generation, Levelised Energy Cost (LEC) is determined by equation 1 (IEA 1991).

$$LEC = \frac{I + L_e + M}{E_T \sum_{t=1}^{n} \frac{1}{(1+k_n)^t}} \qquad (1)$$

Where

I = discounted investment cost

L_e = discounted sum of fuel costs

M = discounted sum of operating expenses

ET = annual useful Useful energy produced

k_n = discount rate in year n

A lifetime of 20 years and a discount rate of 7% are assumed. For technologies that do not supply or displace energy at the point of use, the LEC is multiplied by a factor of 1.84 to simulate retail mark-up[2].

1 Two axis tracked direct and diffuse radiation

2 Based on the ratio of calculated LEC for natural gas electricity generation and the current retail price of electricity (14c/kWh)

2.1. Reference Case

The reference load has been created in order to demonstrate the result of load growth and increased energy use until 2050. It is assumed there is no increase in renewable energy contribution from 2005 levels. Increased uptake of refrigerative air-conditioning and energy intensive appliances is assumed to result in load growth of 3% per annum over the period 2005 – 2015. The load is then assumed to grow at 1.6%[3] from 2015 – 2050. The resultant reference load is over three times greater than the load in 2005 and the peak increases from 50MW to 150MW. CO_2 reduction by intermittent renewables for this reference case is limited.

2.2. Using Energy Efficiency to Reduce the Load

To achieve a 60% CO_2 reduction below 2005 levels the reference load emissions would need to be reduced by almost 90%. This reduction can not be achieved by renewables alone for this study's life cycle CO_2 emission assumptions. By first reducing emissions by energy efficiency measures and fuel switching, the contribution required by renewables becomes more realistic.

Table 1 describes the levelised energy costs and life cycle CO_2 emissions assumed for the demand side measures.

Table 1 Demand Side Energy Costs and CO_2 Emissions Used for the Model (2005$)

	Capital Cost (Million $/MW)	Operation and Maintenance ($/MWh)	Fuel Cost ($/MWh)	End Use LEC ($/MWh)	CO_2 Emissions (kg/MWh)
Energy Efficiency	3.3	5	0	40	0
Domestic Natural Gas	0.7	20	14	95	292[4]
Solar Hot Water	2.2	5	0	30	90

Using information on current energy use breakdowns in Alice, Solar hot water and domestic natural gas contributions to the 2050 load have been calculated and results are presented in Table 2. SWH is assumed to supply 80% of residential hot water needs. Domestic natural gas is used for the remaining hot water use, cooking and space heating.

The demand side measures result in contributions of 39% energy efficiency, 18% domestic natural gas and 10% solar hot water. The remaining 24% is electric load. This electricity load is very similar in shape to the 2005 load; it is assumed there have been no drastic load shape manipulation efforts (for example time of use metering). Compared with the reference case, the energy efficient load has 66% lower CO_2 emissions. These demand side measures provide the necessary starting point for continued emission reduction by renewables.

3 Current population growth of Alice Springs ABS. (2006). "2001 Census Community Profile Series : Alice Springs (Urban Centre/Locality)." Retrieved 5th October, 2007, from http://www.abs.gov.au/websitedbs/D3310114.nsf/home/census%20redirect.

4 Based on conversion efficiency of 80% and natural gas prices of $3.16/GJ

Table 2 Demand Side Contribution and Costs (Sustainable Energy Authority Victoria, Armstrong et al. 2003)

	A/C & Building	Refrigerator	Lighting	Ventilation	Misc.	Space Heating	Cooking	Hot Water
En. Effic. Reduction Residential (%)	67	75	75	-	40	-	-	-
En. Effic. Reduction Commercial (%)	67	-	-	70	40	-	-	-
Solar Hot Water (%)	-	-	-	-	-	-	-	80
Domestic Gas (%)	-	-	-	-	-	100	100	20
Cost per unit ($)	5300	200	200	300	725	-	-	2100 (SHW)
Unit Description	Ceiling, wall & floor insulation, draft sealing, window treatments, shading. 6 star AC	Fans, door seals, improved compressors, insulation and power factors	Efficient lighting and distribution systems	Optimised natural ventilation	Improved clothes washer, dish washer, computers and other miscellaneous appliances	Natural Gas heating	Natural Gas Stove	Solar Hot Water System

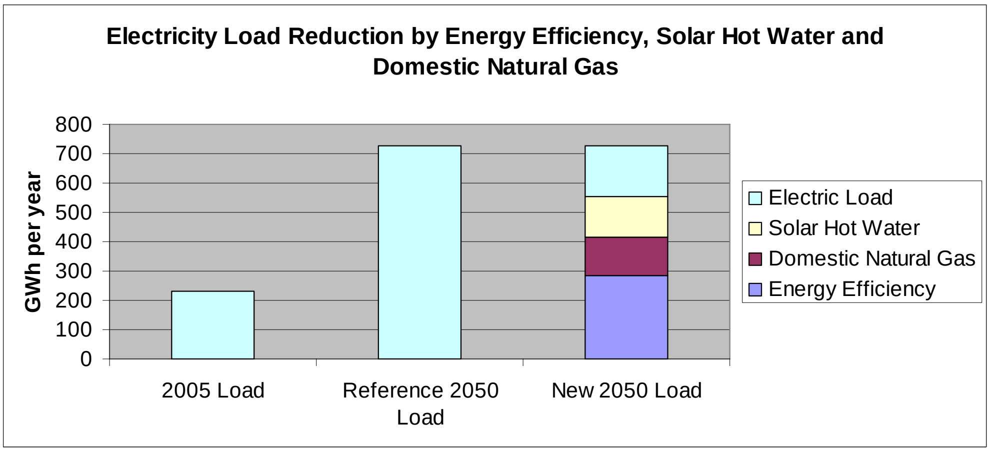

Figure 1 Demand Side Measures Contribution to Load

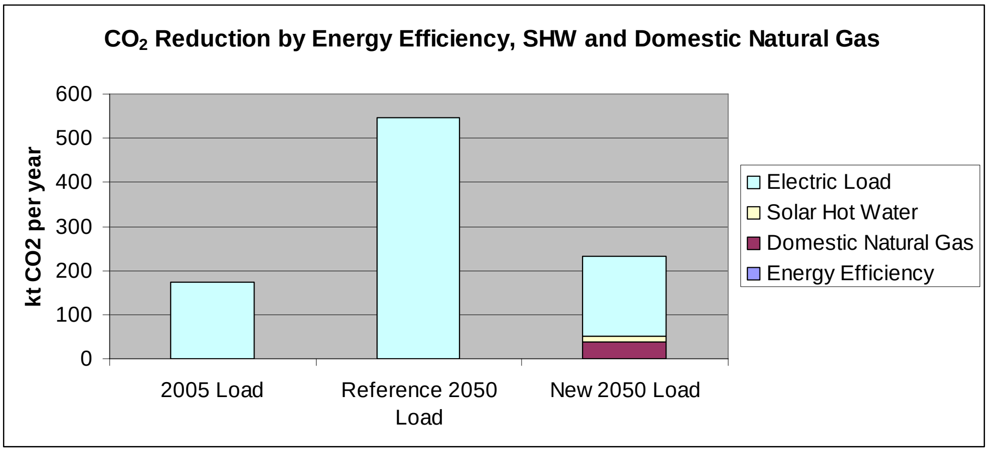

Figure 2 CO_2 Reduction by Demand Side Measures

3. GENERATION

Six generation types have been modeled: rooftop solar photovoltaics, concentrator photovoltaics, wind energy, municipal waste gas, solar thermal parabolic troughs with thermal storage and open cycle natural gas generation. The renewables have been modeled based on hourly weather data for 2005.

The municipal waste gas (MWG) generation upper limit of 0.65MW has been calculated assuming 2050 population of 60 000. The emission reduction potential for these generation technologies is calculated as per the AGO's online handbook (AGO 2005). The greenhouse reduction potential for waste gas generation is large considering landfill and municipal waste gas is currently not collected and flared; waste gasses have a high percentage of methane which has 21 times the warming potential of CO_2.

All direct solar insolation manipulation has been carried out using equation 2: Direct beam intensity on a panel of arbitrary orientation and tilt (Sproul 2007).

$$\cos\theta = -\sin\beta\sin\gamma\cos\delta\sin\omega + \sin\beta\cos\gamma\sin\delta\cos\phi - \sin\beta\cos\gamma\cos\delta\sin\phi\cos\omega + \cos\beta\cos\delta\cos\phi\cos\omega + \cos\beta\sin\delta\sin\phi \quad (2)$$

θ = The angle between beam and normal to the array
β = tilt of the plane γ = azimuth
ω = hour angle δ = declinatio n
ϕ = latitude

For Concentrator PV, direct solar insolation is two axis tracked and thus theta is set to 0. The solar thermal parabolic dishes have been modeled such that they track the sun from east to west on a north to south axis. To simulate this, the azimuth is set to 90^o and the tilt changes hourly to equal the negative hour angle.

In order to add diffuse radiation, the total insolation on a flat plate with arbitrary tilt is given in equation 3 (Morrison 2005).

$$I_T = I_b R_b + I_d \frac{1+\cos\beta}{2} + \left(I_b + I_d\right)\left(\frac{1-\cos\beta}{2}\right)\rho \quad (3)$$

I_T = total insolation on a flat plate I_b = beam/ direct insoaltion on the flat plate
R_b = ratio of insolation absorbed I_d = diffuse component of the radiation
ρ = reflectivity of the surroundings

For rooftop PV, equations 2 and 3 are used with a tilt of 24 degrees and an azimuth of 0 degrees. While the rooftop PV capacity factor over the year is 21%, one axis tracking solar thermal results in 25%. The two axis tracking concentrator PV results in a capacity factor of 32%.

The average wind speed (for Alice Springs airport) in 2005 of $3.8ms^{-1}$ has been scaled logarithmically with a z_0 value of 0.01 to give a yearly average of $5ms^{-1}$ at a 108m hub height. When superimposed on the power curve for the Enercon E82 wind turbine, a capacity factor of 15% results.

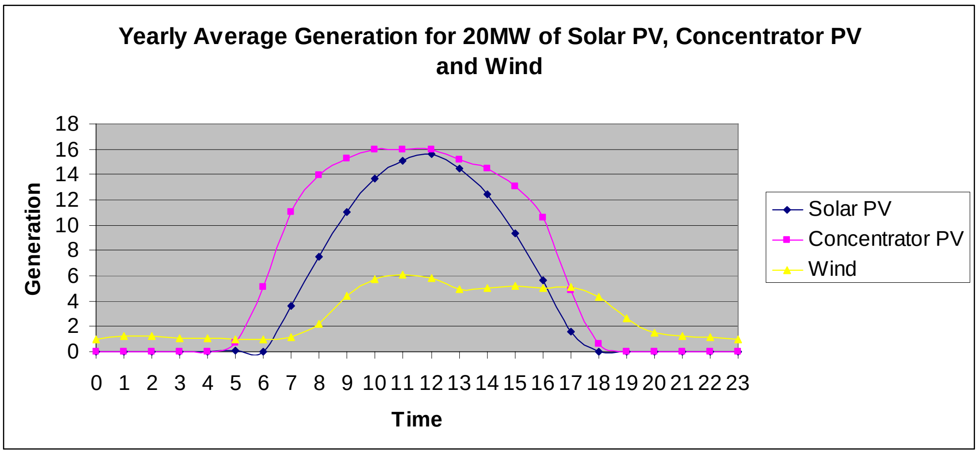

Figure 3 Yearly Average Generation for 20MW of Solar PV, Concentrator PV and Wind Energy

Solar thermal generation is modeled with 12 hours of full capacity thermal storage. The model puts excess solar thermal generation into storage, provided the capacity is not full, and draws on the storage when there is a shortage (illustrated in Figure 4).

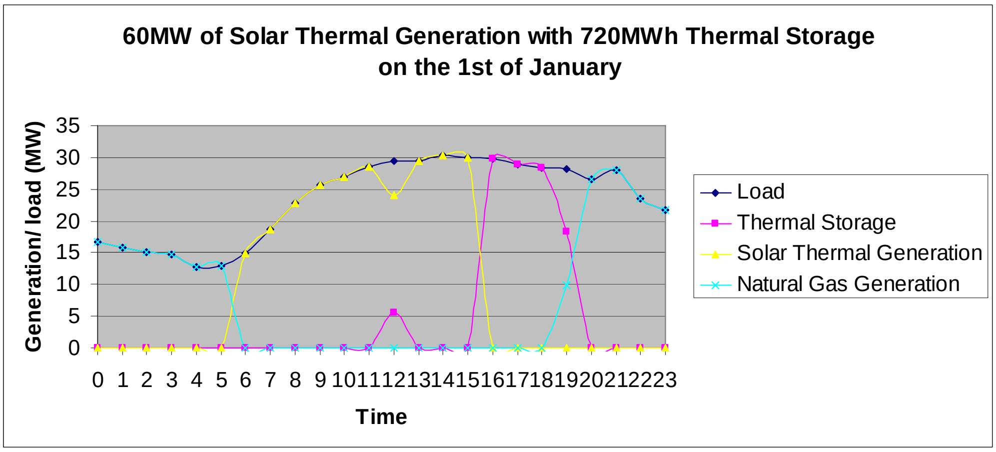

Figure 4 Solar Thermal Generation with Storage on the 1st of January

Figure 4 also illustrates the natural gas open cycle generation, which is modeled to generate when there is insufficient renewable generation to meet the load.

Table 3 summarises the cost and emission reduction assumptions used for this model. The levelised electricity costs (LEC's) for the renewable technologies are displayed for the case where all of their generation is used. However, these prices increase when there is generation above the load and not all energy can be used. For natural gas, the LEC displayed assumes the entire load is met by this generation alone. However, if renewables lead to a lower capacity factor for the natural gas generation, the LEC will increase.

Table 3: 2050 Generation Costs and Life Cycle Emissions

	Capital Cost[5] (Million $/MW)	Capital Cost With cost reduction via learning curves to 2050[6] (Million $/MW)	Operation and Maintenance ($/MWh)	Fuel Cost ($/MWh)	Transmission Cost (Million $/MW)	End Use LEC With no cost reduction ($/MWh)	End Use LEC With cost reduction via learning curves to 2050 ($/MWh)	CO_2 Emissions (kg/MWh)
Solar PV	12.5	3	10	0	0	558	141	150
Concentrator PV	6.35	2	30	0	0.1	431	178	90
Wind	1.7	0.9	5	0	0.1	238	136	23
Solar Thermal	3.4	0.9	30	0	0.1	317	130	90
Thermal Storage	0.05 (per MWh)	0.013	30	172[7]	0	651	540	90
Municipal Waste gas	1[8]	1	20	0	0.1	57	57	-4739/0[9]
Natural Gas Open Cycle	1	1	20	32[10]	0.1	140	140	751

5 Capital Costs for Renewables, operation and maintenance and transmission costs are estimated using Price, H. and D. Kearney (2003). Reducing the Cost of Energy from Parabolic Trough Solar Power Plants. International Solar Energy Conference. Hawaii Island, Hawaii, National Renewable Energy Laboratory.

McLennan Magasanik Associates (2006). Renewable Energy – A Contribution to Australia's Environmental and Economic Sustainability, Renewable Energy Generators Australia Ltd.

6 Capital cost learning curves are taken from McLennan Magasanik Associates (2006). Renewable Energy – A Contribution to Australia's Environmental and Economic Sustainability, Renewable Energy Generators Australia Ltd.

7 This is the cost of solar thermal generation without retail mark-up

8 Based on guidelines for reticulation, metering and service costs in McLennan Magasanik Associates (2004). Economic Analysis of Impact of BCA and Plumbing Regulations on Gas Supply to New Estates, Department of Infrastructure and the Sustainable Energy Authority Victoria (SEAV).

9 Waste gas generation displaces 2005 methane levels after which time waste methane is assumed to have been otherwise flared

10 Assuming thermal efficiency of 35% and natural gas cost of $3.16 /GJ ABARE (2006). Energy in Australia 2006, Australian Government Department of Industry, Tourism and Resources.

4. 25% RENEWABLE ENERGY TARGET

In this scenario the model has been optimised to find the lowest cost, highest emission reduction solution when 25% of the load is met by renewable generation.

For this level of renewable energy penetration, very little renewable generation is wasted. All of the technologies performed fairly equally, including combinations of renewables. 37MW of Wind energy combined with 0.65MW MWG gave the best result, followed closely by a combination of 10MW Wind combined with 11 MW of Concentrator PV and 0.65MW MWG. For the case of mixed wind and waste gas generation, the end use cost of electricity is $154/MWh and the end use cost of energy services $77 per MWh with an emission reduction of 20% below 2005 levels. If there was no drop in renewable energy costs by 2050, the cost of energy services would be $78/MWh.

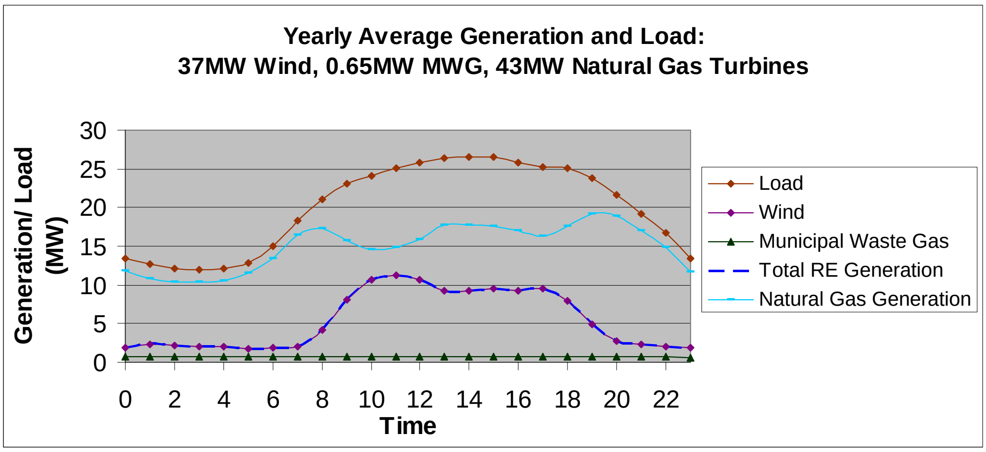

Figure 5 2050 Annual Average Generation and Load for 37MW Wind, 0.65MW MWG

5. 50% RENEWABLE ENERGY TARGET

The lowest cost, highest emission reduction mix of generation is found for a 50% renewable energy target. The highest emission reduction and lowest price is achieved with a mix of solar and wind energy: 26MW wind, 26MW concentrator PV and 0.65MW MWG. This suggests the weather patterns for the solar and wind resource are complimentary for this load shape. For this optimal mix, a 35% emission reduction is achieved for an end use electricity price of $190/MWh and an energy service cost of $80/MWh. If there is no decrease in cost for renewables the energy service price would be $110/MWh. The annual average load and generation mix is shown in Figure 7.

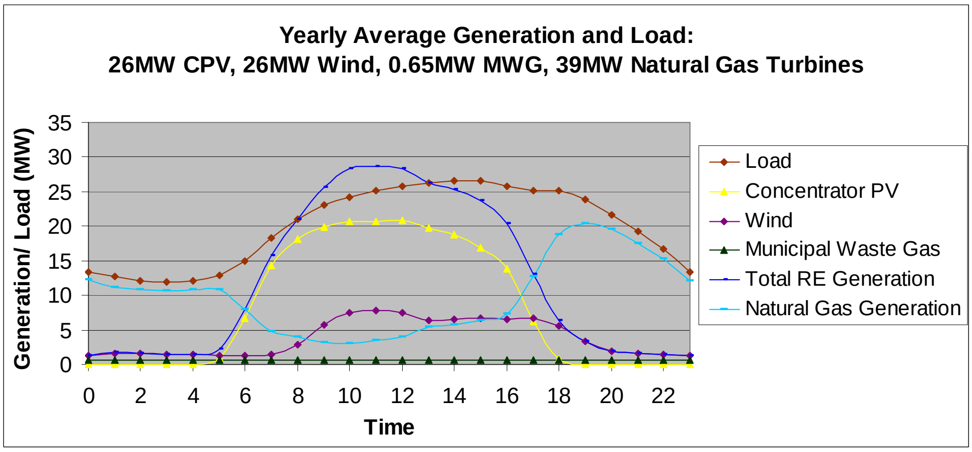

Figure 6 Yearly Average Generation and Load for 26MW, Wind, 26MW Solar and 0.65MW MWG

6. HIGHER RENEWABLE ENERGY CONTRIBUTIONS

As the renewable energy generation capacity for the model is increased, emission reduction increases, however, only up to a certain point. Although renewable contribution keeps increasing, eventually the wasted generation leads to renewable energy life cycle emissions that outweigh the benefit of displacing natural gas. Therefore, while the limit to the renewable energy contribution for the model is close to 100%, the limit to the CO_2 reduction below 2005 levels is 62%. Obviously this is strongly influenced by the life cycle emission assumptions for renewables given in Table 3.

The least cost solution for a 62% reduction is achieved by 0.65MW of Municipal Waste Gas generation with 100MW of solar thermal energy and corresponding thermal storage capacity of 1200MWh (Figure 7). While the cost of electricity for this scenario is reasonably high at $483/ MWh, the cost of energy services is $150/MWh: approximately the current retail price. If there is no assumed decrease in renewable energy costs by the year 2050, the cost of energy services is $216/MWh which is still quite low. The renewable contribution to the load for this case is 94%. There is wasted generation for this case (20%) when it is sunny but the storage is full which warrants the investigation of higher storage capacities in future studies.

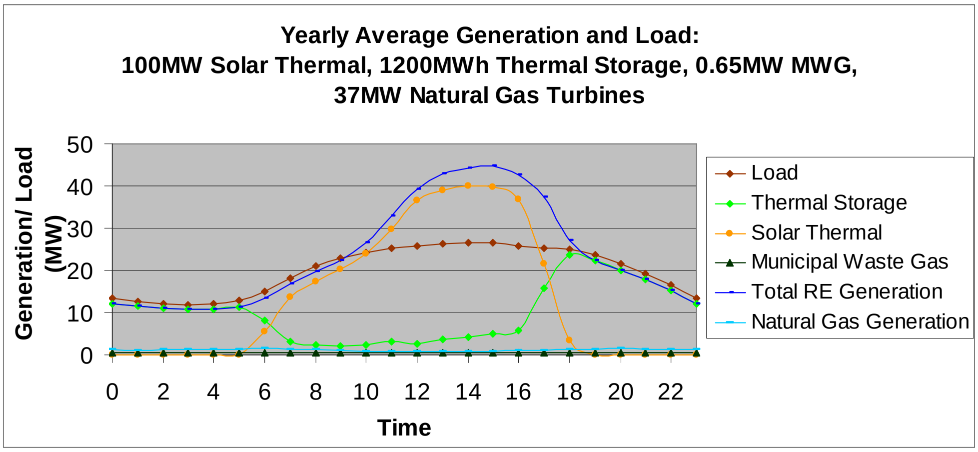

Figure 7 Yearly Average Generation and Load for Lowest Cost, Maximum Emission Reduction

7. DISCUSSION AND CONCLUSIONS

This study has modelled future scenarios for meeting electricity demand in the year 2050. Demand side measures coupled with renewable generation, given these models assumptions, can achieve a 60% CO_2 reduction with a small increase in the price of energy services.

The load growth described in the reference case creates a scenario where emission reduction requires huge changes in energy service provision. This emphasises the need to encourage demand side measures which are known to be a cost effective means of emission reduction.

The results of this study suggest that the combination of the wind and solar resource can be more cost effective than using either of these technologies alone. At very high levels of renewable penetration, the higher costs for thermal storage become worthwhile. The relatively low cost of energy efficiency, SHW and domestic natural gas assumed in this model, compensates for even very high renewable energy penetrations.

Although future scenario modeling is built on a large number of assumptions and cannot provide concrete answers, results highlight opportunities that can be overlooked in conventional planning methods. The results from this study suggest future considerations might include:

- Further investigation of the wind resource in Alice Springs particularly regarding increased wind speed at wind turbine hub heights to investigate thermal effects
- Consideration of the potential for solar and wind resource complimentary effects
- Emission reduction efforts which consider renewable generation to be necessarily coupled with demand side measures that increase efficiency and reduce waste of energy
- Further study of the potential for solar thermal generation with various storage capacities.

8. ACKNOWLEDGEMENTS

Special thanks to Steve Sawyer, Mark Dodemond, David Adams and of course my supervisors Muriel and Iain.

9. REFERENCES

ABARE (2006). Energy in Australia 2006, Australian Government Department of Industry, Tourism and Resources.

ABS. (2006). "2001 Census Community Profile Series : Alice Springs (Urban Centre/Locality)." Retrieved 5th October, 2007, from http://www.abs.gov.au/websitedbs/D3310114.nsf/home/census%20redirect.

AGO. (2005). "Methane Capture and Use Waste Mangement Workbook." Retrieved 3rd August, 2006, from http://www.greenhouse.gov.au/challenge/publications/methanequickref.html.

Alice Springs Town Council. (2007, 5th January). "Alice Springs." Retrieved 4th June, from http://www.alicesprings.nt.gov.au/.

Bureau of Meteorology (2006). Alice Springs Airport Houlry Data.

CSAT (2005). Solar Hot Water performance in Alice Springs, Centre for Sustainable Arid Towns.

Focken, U. and M. Lange (2006). A Physical Approach to Short Term Wind Power Prediction, Springer - Verlag Berlin Heidelberg

IEA (1991). Guidelines for the ecconomic analysis of renewable energy technologies, Organisation for Ecconomic Co-operation and Development (OECD) / International Energy Agency (IEA.

McLennan Magasanik Associates (2004). Economic Analysis of Impact of BCA and Plumbing Regulations on Gas Supply to New Estates, Department of Infrastructure and the Sustainable Energy Authority Victoria (SEAV).

McLennan Magasanik Associates (2006). Renewable Energy – A Contribution to Australia's Environmental and Economic Sustainability, Renewable Energy Generators Australia Ltd.

Morrison, G. (2005). MECH 9720: Solar Thermal Energy Course Notes, UNSW.

Picton, J. (2007). Scenario Analysis of Possible Sustainable Energy Futures for Alice Springs. School of Photovoltaic and Renewable Energy Engineering Sydney, UNSW.

Power and Water. (2006). "About Us." Retrieved 1st October, 2006, from http://www.powerwater.com.au/powerwater/aboutus/index.html.

Power and Water. (2006, 1st July 2006). "Home Power Tariffs." Retrieved 5th May, 2007, from http://www.nt.gov.au/powerwater/customers/tariff_home_power.html.

Price, H. and D. Kearney (2003). Reducing the Cost of Energy from Parabolic Trough Solar Power Plants. International Solar Energy Conference. Hawaii Island, Hawaii, National Renewable Energy Laboratory.

Sproul, A. (2007). "Derivation of the Solar Geometric Relationship Using Vector Analysis " Renewable Energy Journal **Volume 32**: 1187-1205.

Sustainable Energy Authority Victoria, G. Armstrong, et al. (2003). Preliminary Assessment of Demand-Side Energy Efficiency Improvement Potential and Costs, Energy Efficiency and Greenhouse Working Group.