CEEM Seminar 29/3/2006

Scenarios for Australian Clean Energy Futures

Can Renewable Energy Substitute for Coal Power?

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PROGRAM

1. National clean energy scenarios for 2040 reviewed
2. Substituting for proposed new coal-fired power stations with clean energy mixes by 2012
3. Integration of wind power into electricity grids: economic value of wind power

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Part 1:
NATIONAL CLEAN ENERGY SCENARIOS FOR 2040

Authors

- **Dr Hugh Saddler**, Energy Strategies Pty Ltd, on future energy demand with and without efficiency
- **Dr Mark Diesendorf**, Sustainability Centre Pty Ltd (now IES, UNSW) on future energy supply
- **Richard Denniss**, Australia Institute (now economic adviser to Australian Greens) on present and future economic structure of Australia

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AIM: BIG REDUCTIONS IN CO_2 EMISSIONS FROM STATIONARY ENERGY

Stationary energy	Electricity (grid-connected & remote); residential heat; industrial heat and engines
Long-term target	Reduction to 50% of 2001 CO_2 emissions by 2040
Technologies	Small changes to existing technologies
Economic growth	Continuing

i.e. Big reduction without major technical breakthroughs!

EXISTING TECHNOLOGY
WITH SMALL IMPROVEMENTS

- No cheap solar electricity
- No cheap H_2 from renewables or cheap batteries
- No cheap hot rock geothermal
- No cheap carbon capture and geosequestration
- No cheap nuclear power

Some or all of these may be possible before 2040.

DRIVERS OF ENERGY CONSUMPTION & GHG EMISSIONS

$I = P \times A \times T$

Environmental Impact = Population x Affluence x Technology

where Affluence A = GDP / person

and Technology T = Impact / GDP

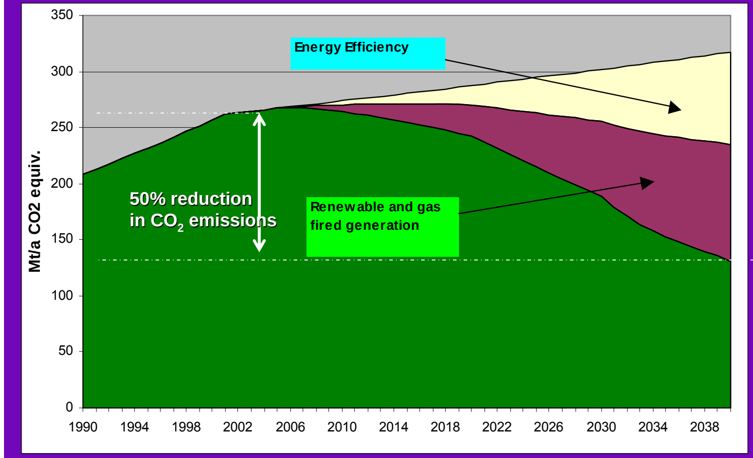
Population growth 2001 to 2040 ~ 29% to 25 million (ABS)

Annual GDP growth from Intergenerational Report:

Technology improvements: included in study

My personal view: we need population and affluence policies now. Endless GDP growth doesn't necessarily trickle down.

RESULTS: CO_2 EMISSIONS FROM STATIONARY ENERGY, AUSTRALIA



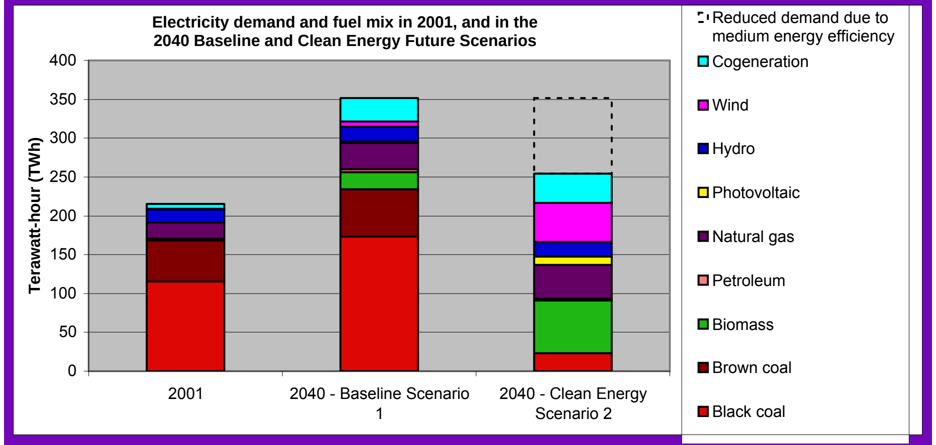
Baseline

Baseline with medium efficiency

Clean Energy Future

The time path is a notional one, based on the assumption that policy recommendations are adopted.

ELECTRICITY FUEL MIX IN 2001, 2040 BASELINE, & 2040 SCENARIO 2



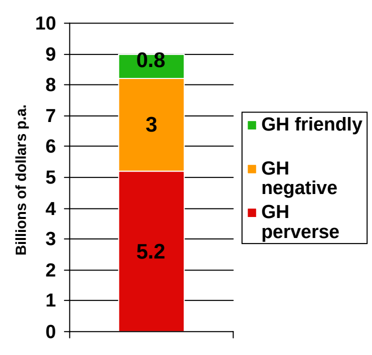
% CHANGE IN CO_2 EMISSIONS IN 2040 RELATIVE TO 2001, SCENARIOS 1 - 3

Scenario	**From electricity**	**From stationary energy other than electricity**	**From all stationary energy**
1. Baseline demand (weak efficiency), 'dirty' supply mix	+14%	+37%	+21%
2. Medium efficiency, low coal	**-78%**	**+12%**	**-50%**
3. Medium efficiency, 0 coal	-85%	+12%	-55%

With existing technologies, electricity emission reductions are easiest.

FOSSIL FUEL ECONOMIC SUBSIDIES BY CATEGORY

in $ billion p.a. (Riedy & Diesendorf (2003); Riedy, 2003)



'Perverse' subsidies increase GHG emissions AND reduce economic efficiency

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PRINCIPAL FOSSIL FUEL SUBSIDIES

- Electricity for aluminium smelting
- Infrastructure for air conditioning etc.
- Salary packaging for motor vehicles
- Greenhouse Gas Abatement Program
- Fuel excise reduction
- Fuel sales grants
- Automotive industry support
- Land for roads & parking
- Reduced import duty on 4WDs
- Inappropriate company tax concessions
- R&D
- Non-recovery of government agency costs

SUMMARY

- 50% emissions reduction target is technically feasible and compatible with continued economic growth.
- Target cannot be achieved with business-as-usual demand growth and small improvements in coal-burning technologies.
- Between now & 2040 we can replace most energy-using equipment with more efficient versions at little or no net cost.
- Natural gas, wind power, bioenergy and solar hot water could each make a big contribution to energy supply in 2040.
- Uncertainty whether there is any net cost at micro level.
- Need policies to remove market barriers & build industry.

Part 2:

Replacing a NSW 1000 MW Coal-Fired Power Station with a Clean Energy Mix by 2012

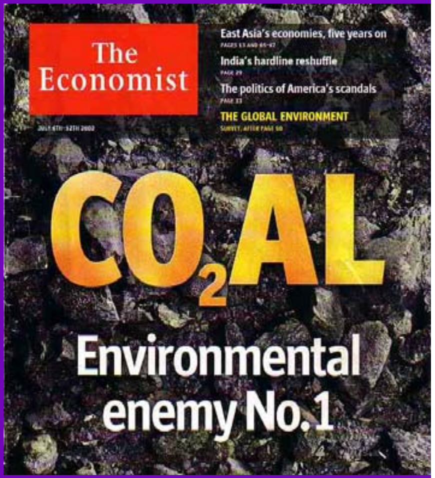
FOCUS OF NSW STUDY

Clean energy mix ….

- Substitutes for both annual electricity generation and equivalent firm capacity of a 1000 MW coal-fired power station by 2010.
- Obtains 80% reduction in CO_2 emissions, compared with that of coal-fired power station.
- Uses best practice existing technologies

WHY TARGET COAL?

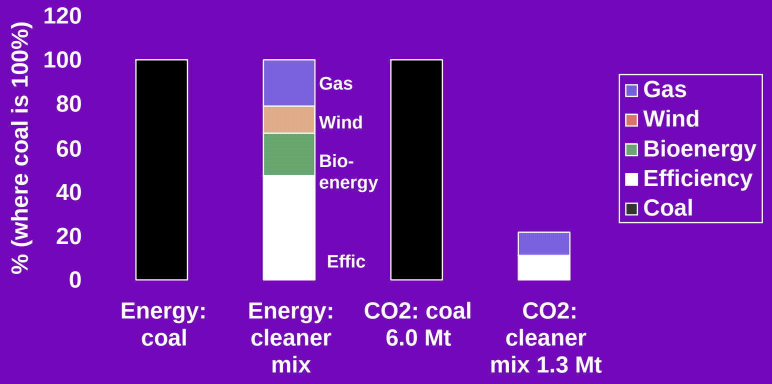
- Most greenhouse-intensive fossil fuel
- Building coal-fired power stations undermines energy efficiency programs



The Economist, 6-12 July 2002

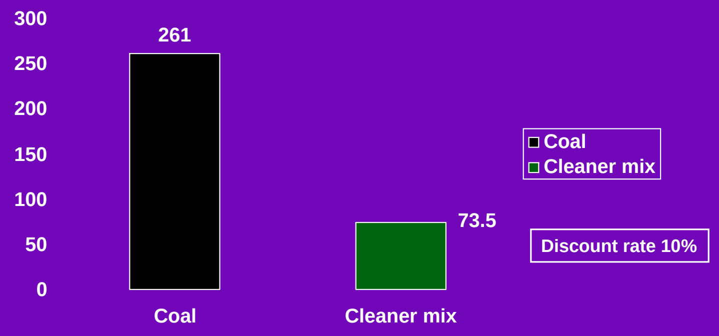
SUBSTITUTING FOR A 1000 MWe NSW STN:

Annual Energy Generation & CO_2 Emissions



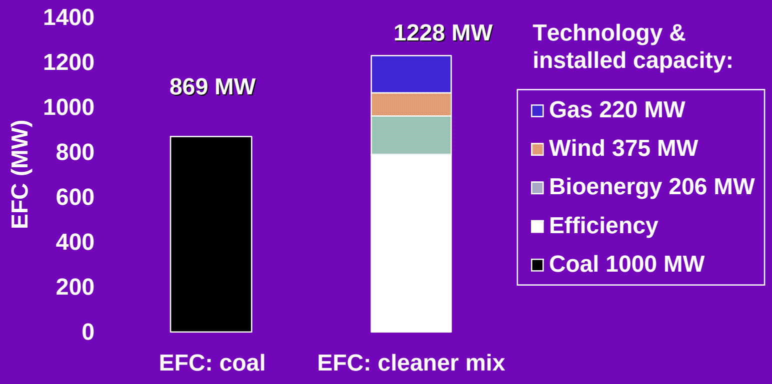
Cleaner mix achieves 80% reduction in CO_2 emissions

NSW STUDY: COSTS OF ENERGY DELIVERED IN YEAR 6



$ savings from energy efficiency pay for additional costs of gas & renewable energy and more -- provided institutional changes are made. Network costs not included.

NSW STUDY: EQUIVALENT FIRM CAPACITY 1000 MW coal station and alternative mix



SOME RECOMMENDED POLICIES:

DEMAND SIDE

- Energy performance standards for several categories of existing buildings, commencing with tenanted
- Incentives/penalties to encourage expansion of solar hot water
- Smart meters and peak-load pricing for air conditioners
- Low-cost packages for householders

INFRASTRUCTURE FOR AIR CONDITIONING

- New peak-load power stations
- Extensive upgrades to power lines to carry peak loads
- Actual cost per 5 kW air conditioner (single phase) ~ $1500 p.a. for 10 yr (BCSE, 2003)
- Consumer pays only $60 p.a.
- One possible solution: ‘smart meters’ and peakload pricing

SOME RECOMMENDED POLICIES:
SUPPLY SIDE

- Limit on greenhouse intensity of all new power stations.
- State Mandatory Renewable Energy Target (MRET)
- Either tradeable emission permits (cap & trade type) or carbon levy
- Remove subsidies to production and use of fossil fuels

Part 3:

Integration of Wind Power into Grids:

Capacity Credit and Optimal Mix

RELEVANCE TO ENERGY MARKETS

- Rules for integrating wind power and other variable renewable energy sources into the grid
- Attempts by vested interests to exclude wind from national energy future scenarios, development plans and funding, and to stop specific wind farm proposals
- UK Energy Review: wind Vs nuclear struggle

CAPACITY CREDIT OF WIND POWER
Fallacies

“A single [rare] heat-wave, during which there was no wind, demonstrates that wind power is unsuitable for providing electricity to the grid.”

“Wind power cannot contribute more than 5% (or 10%) of electricity to a grid, until cheap electrical storage is developed.”

“1000 MW of wind capacity requires back-up of 1000 MW.”

“1000 MW of wind capacity, with capacity credit of 200 MW, requires back-up of 800 MW.”

CAPACITY CREDIT OF WIND POWER
Incorrect Approaches

- Classify thermal power stations as 'reliable' and wind and solar as 'intermittent' = unreliable.
- Place arbitrary requirements on performance of wind farms.
- E.g. "firm capacity of a wind farm is that percentage of installed capacity that is statistically available for at least 95% of time" -- ESIPC
- Obtain absurd results: e.g. ESIPC: "Wind power has firm capacity ~8% of installed capacity" (independent of wind penetration into grid!!)

CAPACITY CREDIT OF WIND POWER
Correct Approaches

1. Recognise 3 random variables: demand or load L(t), availability of thermal power stations A(t), wind power W(t)
2. Define reliability of whole generating system:
   e.g. LOLP = Pr (A < L)
   or a measure of frequency & duration of forced outages
3. Evaluate reliability of whole generating system with & without wind power.
4. Then some meaningful measures of capacity credit are Equivalent Firm Capacity (EFC) and Effective Load Carrying Capability (ELCC)

LOLP METHOD FOR CALCULATING EFC

Grid with thermal capacity C of which A(t) is available at time t. In absence of wind power

p_0 = Pr (A < L).

Add hypothetical 100% firm capacity C_F. Then

p_f = Pr (A + C_F < L).

Alternatively add non-firm capacity W_r, random variable W(t)

p_W = Pr (A + W < L)

Then EFC of wind is value of C_F obtained from equating

$p_f = p_W$,

given probability distributions for A, L and W.

LOLP METHOD FOR CALCULATING ELCC

If non-firm capacity W_r is added to grid, ELCC is the value of firm load C_L added to L(t) such that

p_0 = Pr (A + W < L + C_L).

i.e. ELCC is amount by which load may be increased in presence of additional non-firm capacity while original LOLP of p_0 is maintained.

3 METHODS OF EVALUATING EFC

1. Dynamic computer simulation using real hourly data for L(t), A(t) and W(t). Automatically includes correlations. (Several authors 1978-present.)
2. Numerical convolution of empirical probability distributions ignoring time sequence (i.e no correlations but fast sensitivity analysis) (Martin & Diesendorf, 1980)
3. Analytic solutions using Normal distributions for L (good) and A (poor), and a realistic distribution for W; no correlations (Haslett & Diesendorf, 1980)

RESULTS: NUMERICAL PROBABILITY DISTRIBUTIONS, STATIC APPROACH

(Martin & Diesendorf, 1980)

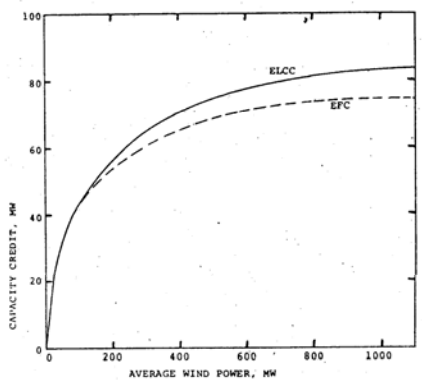


Fig. 2 Capacity credit as a function of wind penetration for the WA grid and 'standard' aerogenerator characteristics.

Simplified WA grid of 1978
<L> = 513 MW.

$p_0 = 2.3\times10^{-4}$

Normal distributions for A(t) & L(t)

All Wind at Single Site. Rayleigh distribution of wind speeds.

For small penetration, capacity credit (MW) = average wind power.

RESULTS: NUMERICAL PROBABILITY DIST'NS

All wind at single site

Wind penetration <W>/<L> (%)	EFC/<W> (%)
0	100
2.1	85
4.2	75
7.5	62
12.5	51
20.9	39
33	30
50	23

Results also sensitive to size of thermal units & start-up wind speed.

RESULTS: ANALTIC APPROXIMATIONS

All Wind at Single Site

(Haslett & Diesendorf, 1980)

Assume Normal distributions for L (good) & A (poor) and a realistic model of W.

Exact expression derived for p_W. Then:

In limit of small wind power penetration:

$$p_W \approx p_0\,[1 - z_0^2.\langle W\rangle/(\langle A_0\rangle - \langle L\rangle)]$$

where z_0 is given by $F(z_0) = p_0$, where $F(z_0)$ is related to standard Normal distribution function and is tabulated. Then

$$EFC \approx \langle W\rangle[1 + O(\langle W\rangle/(\langle A_0\rangle - \langle L\rangle))]$$

1st order terms all evaluated but messy.

RESULTS: ANALTIC APPROXIMATIONS
All Wind at Single Site

In limit of large wind power penetration:

$p_w \rightarrow p_\infty = p_0 \,.\, \Pr(W=0)$

EFC $\rightarrow p_0 \,.\, \Pr(W=0) \times$ parameters

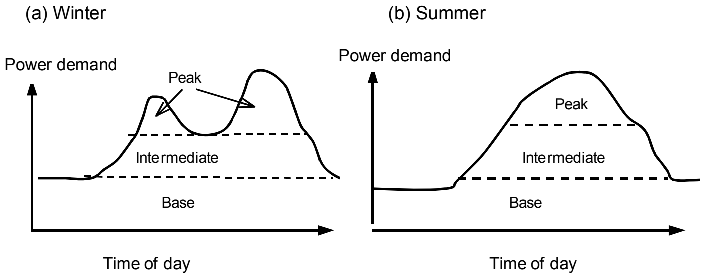
EFC calculated for conventional plant too. Maximum size for thermal power station in given generating system and given p_0.

ECONOMIC IMPLICATIONS: OPTIMAL MIX OF THERMAL PLANT

- Capacity credit does not determine whether wind substitutes for base-, intermediate- or peak-load thermal power stations.
- i.e. capacity credit alone does not give economic information.
- Hence evaluate optimal mix of generating system with and without wind power.

BALANCING SUPPLY & DEMAND
With Mix of Base-, Intermediate & Peak-Load Plant

Fig. 6: Typical power demand (load) by time of day in (a) winter and (b) summer, showing contributions of base-, intermediate- and peak-load plant



PROPERTIES OF BASE-, INTERMEDIATE- & PEAK-LOAD POWER STATIONS

Type	**Fuels**	**Capital cost (annualised)**	**Operating cost (mostly fuel)**	**Ability to ramp output**	**Capacity factor***
Base	Coal, nuclear, gas	High	Low	Low	High
Intermediate	Coal, gas	Medium	Medium	Medium	Medium
Peak	Gas, oil, hyd	Low (not hydro)	High	High	Low

RECIPE FOR INCORRECT CALCULATIONS

(e.g. ESB 2004 study for Eire grid)

1. Use a complex computer model (e.g. PROMOD) without clarifying its assumptions & limitations
2. Don't reference ***any*** of the scholarly literature.
3. Don't optimise mix of thermal generating system.
4. To compensate for wind variations, use base- or intermediate-load, at great expense, ignoring the fact that peak-load is there to handle short-term fluctuations in supply & demand.

FORMULATION OF STATIC OPTIMAL MIX

Consider grid with identical base- & identical peak-load stations only.
Static optimal mix is configuration that minimises cost function

$$F(N_b) = N_bC_by_b + N_pC_py_p + z_b\sum_i E_i(N_b) + z_p\sum_i E_i$$

where $N_b + N_p = N$, total no. of power stations;
$N_pC_p + N_bC_b = C$, total capacity, determined by
$p_0 = \Pr(A < L)$;
For ith power station, y_i = annualized capital cost/kW rated;
z_i = annual (fuel + O & M cost)/kWh;
E_i = annual *usable* energy generated by ith station
1st sum: $i=1$ to N_b; 2nd sum: $i= N_b + 1$ to N_p

Solution is value of N_b that minimises F.

EVALUATION OF STATIC OPTIMAL MIX

Re-optimisation of mix is generalisation of previous equations with (L - W) replacing L.

LOLP becomes $p_0 = \Pr(A^* + W < L)$,
where A* is available conventional capacity corresponding to reduced conventional capacity C*.

Martin & Diesendorf (1981) used empirical numerical probability distributions, with wind at a single site.

OPTIMAL MIX RESULTS

Over a wide range of cost parameters

- Wind power replaces base-load power stations with approx. the same annual average energy generation
- Thus wind power is both a capital saver and fuel saver. Capital savings are often of similar magnitude to fuel savings.
- In case of single wind site, additional $C_P \approx 0.5$ wind capacity. For multiple wind sites, full calculations not done, but expect 0.2 to 0.3 C_P, depending on spatial correlations.
- For wind energy penetrations < 20% , additional peak-load fuel use is small. Hence additional C_P is reliability insurance with low premium.

CONFIRMATION AND EXTENSION OF RESULTS (Grubb, 1988)

- Multiple sites in UK with real wind data
- Dynamic probabilistic method
- Addresses both operation and optimal mix
- Includes spinning reserve and additional start-ups
- Wind replaces base-load capacity (nuclear)

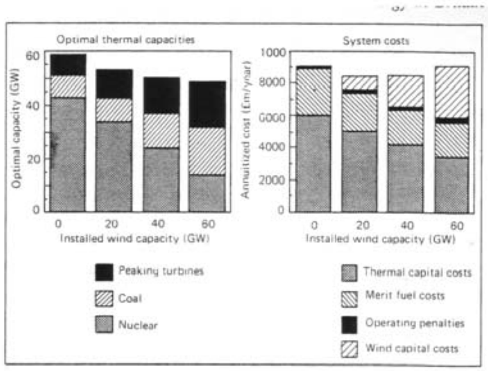


Figure 6. Optimal plant mix and savings for increasing wind capacity on system with unconstrained nuclear capacity.

CONFIRMATION AND EXTENSION OF RESULTS ctd (Grubb, 1988)

- No nuclear
- Wind replaces base-load capacity (coal)

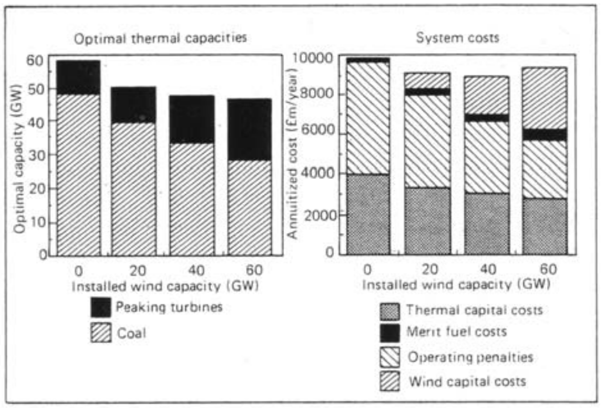


Figure 7. Optimal plant mix and savings for increasing wind capacity on system with no nuclear power.

GENUINE DIFFERENCES IN RESULTS BETWEEN DIFFERENT MODELS

- Failure to reoptimise thermal mix in presence of wind capacity
- Choice of basic parameters:
  - reserve plant capacity;
  - limits to ramping of thermal plant;
  - wind power diversity & predictability
- Operating decisions:
  - Choice of running spinning reserve or starting up peakload

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WIND POWER: CEF SCENARIO

20% of electricity (20 GW, 51 TWh/yr) in 2040

- In practice 20% of electricity achieved in Denmark by end 2003.
- Minor problems, but 20% is not an absolute limit.
- 42% with wind + low-load diesels at Denham & Hopetoun W.A., & Mawson
- Wind + gas turbines can substitute for coal in grid, with less variability & more reserve capacity.
- Need changes to network

Albany wind farm, W.A.

CONCLUSION

- Fallacies mentioned previously are indeed fallacies.
- For small penetrations of wind energy into a grid, variability of wind is lost in variability of demand and existing reserve plant is adequate.
- For medium to large wind energy penetrations, wind substitutes mainly for conventional baseload capacity and fuel. To maintain generation reliability, either some additional peakload or power purchase is required.
- Additional start-ups and ramping of thermal plant, reserve capacity & discarded wind energy may become significant economically above 25-30% wind energy penetrations.

FURTHER READING

- National and state scenario studies available at www.wwf.org.au ; go to 'Climate Change', then 'Publications'.
- Capacity credit of wind power & optimal mix: Martin & Diesendorf (1982,1983, 1980) and Haslett & Diesendorf (1981) at www.sustainabilitycentre.com.au/publics.html
- Grubb MJ 1988, *Energy Policy* 16:594-607; *Wind Engineering* 12:1-26.