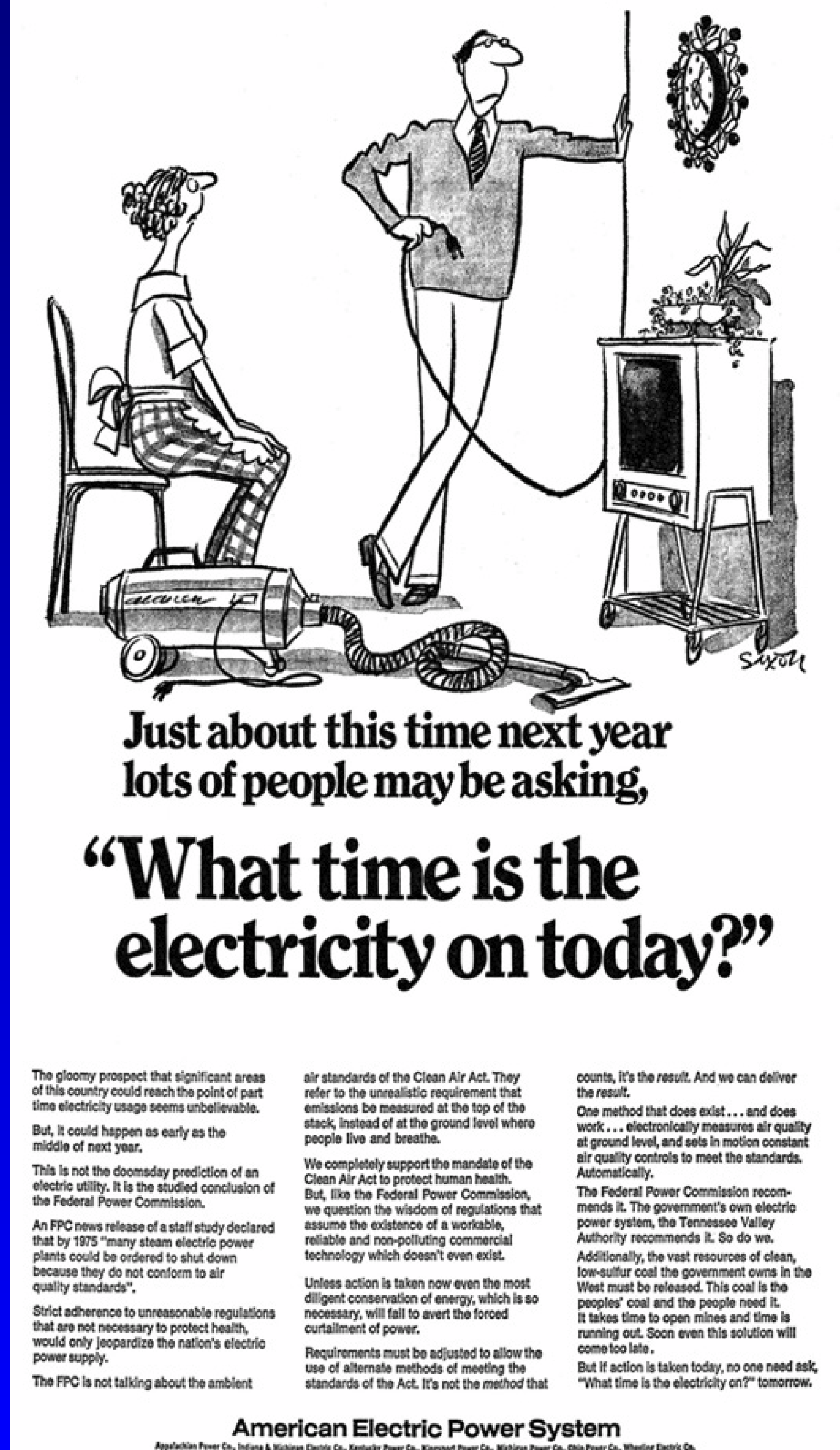
Least cost 100% renewable electricity scenarios in the National Electricity Market

Ben Elliston, Mark Diesendorf, Iain MacGill
University of New South Wales

b.elliston@student.unsw.edu.au



Just about this time next year lots of people may be asking,

"What time is the electricity on today?"

The gloomy prospect that significant areas of this country could reach the point of part time electricity usage seems unbelievable.

But, it could happen as early as the middle of next year.

This is not the doomsday prediction of an electric utility. It is the studied conclusion of the Federal Power Commission.

An FPC news release of a staff study declared that by 1975 "many steam electric power plants could be ordered to shut down because they do not conform to air quality standards".

Strict adherence to unreasonable regulations that are not necessary to protect health, would only jeopardize the nation's electric power supply.

The FPC is not talking about the ambient air standards of the Clean Air Act. They refer to the unrealistic requirement that emissions be measured at the top of the stack, instead of at the ground level where people live and breathe.

We completely support the mandate of the Clean Air Act to protect human health. But, like the Federal Power Commission, we question the wisdom of regulations that assume the existence of a workable, reliable and non-polluting commercial technology which doesn't even exist.

Unless action is taken now even the most diligent conservation of energy, which is so necessary, will fail to avert the forced curtailment of power.

Requirements must be adjusted to allow the use of alternate methods of meeting the standards of the Act. It's not the *method* that counts, it's the *result*. And we can deliver the *result*.

One method that does exist . . . and does work . . . electronically measures air quality at ground level, and sets in motion constant air quality controls to meet the standards. Automatically.

The Federal Power Commission recommends it. The government's own electric power system, the Tennessee Valley Authority recommends it. So do we.

Additionally, the vast resources of clean, low-sulfur coal the government owns in the West must be released. This coal is the peoples' coal and the people need it. It takes time to open mines and time is running out. Soon even this solution will come too late.

But if action is taken today, no one need ask, "What time is the electricity on?" tomorrow.

American Electric Power System

Appalachian Power Co., Indiana & Michigan Electric Co., Kentucky Power Co., Kingsport Power Co., Michigan Power Co., Ohio Power Co., Wheeling Electric Co.

New York Times, 1974

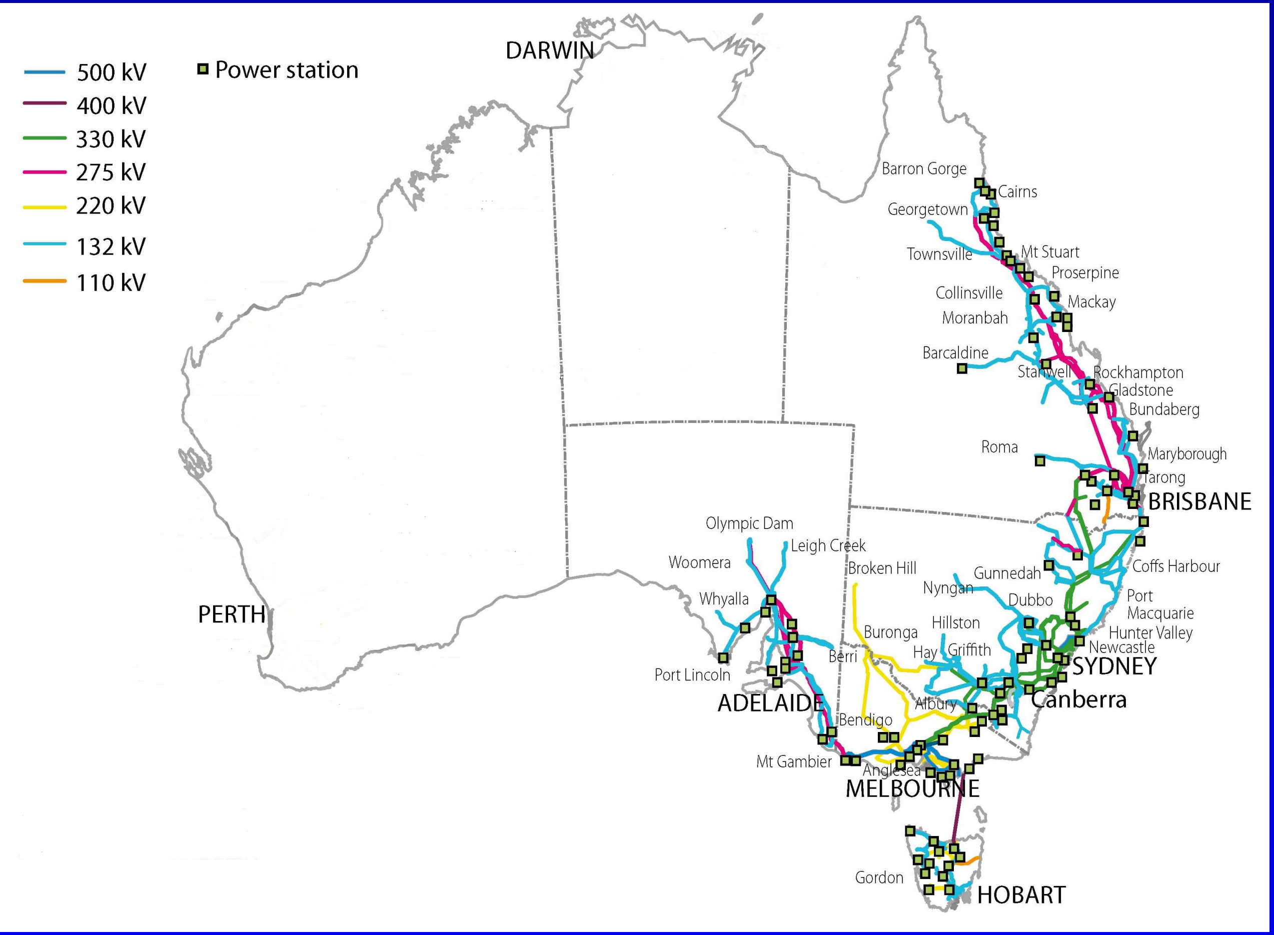
Why 100% renewable electricity?

- AR4 (IPCC, 2007) stablisation target for 2^{o}C
  - 80% to 95% below 1990 emissions by 2050
- Australian Government policy
  - 80% below 2000 emissions by 2050
- Some current jurisdictional RE targets
  - Australia: 20% by 2020
  - Germany: 40% by 2020, 80% by 2050
  - New Zealand: 90% by 2050
  - Denmark: 100% by 2050 (41% in 2011)
- AEMO tasked by MPCCC with 100% modelling

Outline

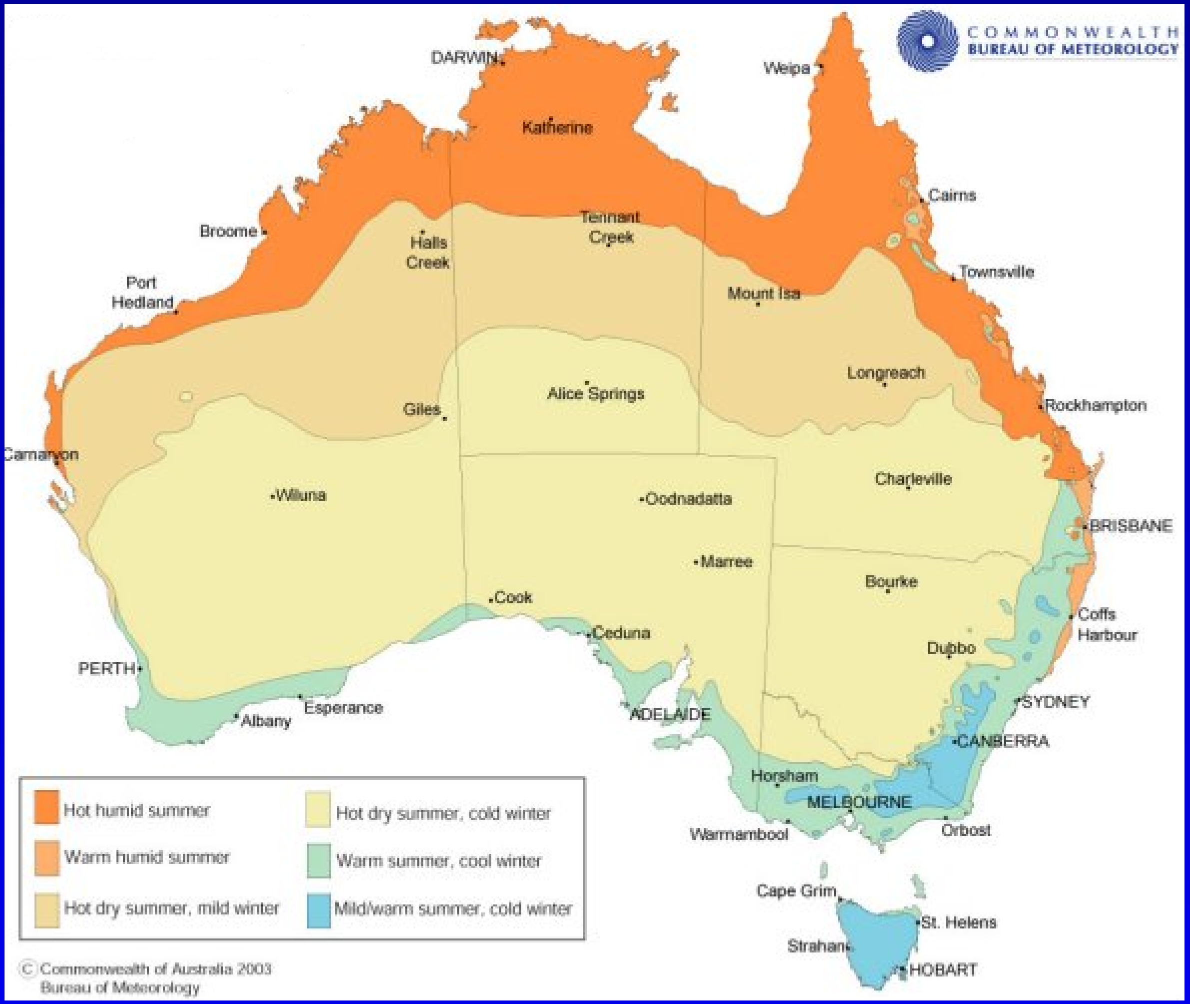
- Background
  - NEM regions
  - Simulations
- Simulation extensions
- Combining simulations with search
- Least cost search results
- Comparison with a reference scenario
- Conclusions

NEM regions



Map of generation and transmission assets in the NEM (Source: Geoscience Australia)

NEM regions



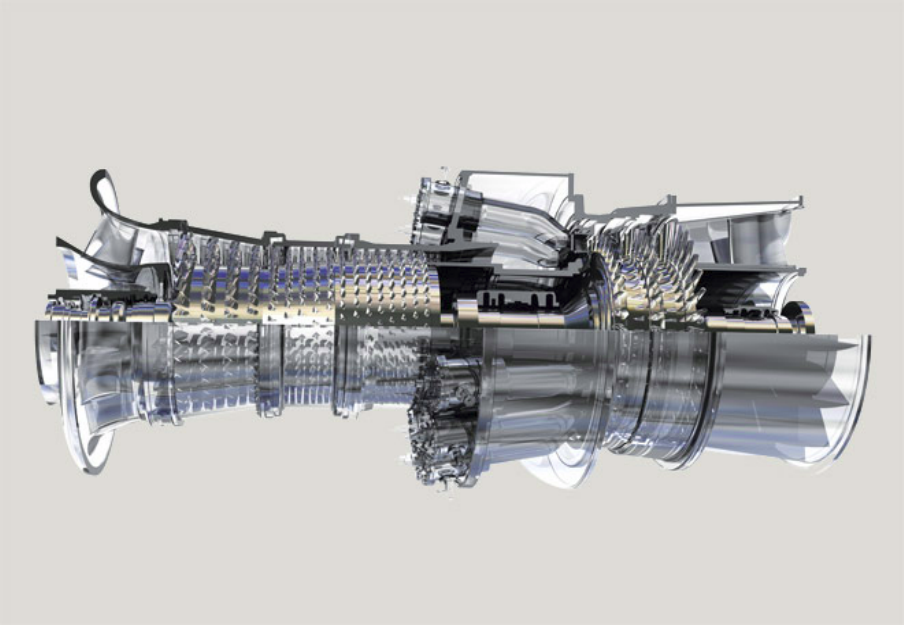
The diversity of Australian climate zones (Source: Bureau of Meteorology)

Simulation background

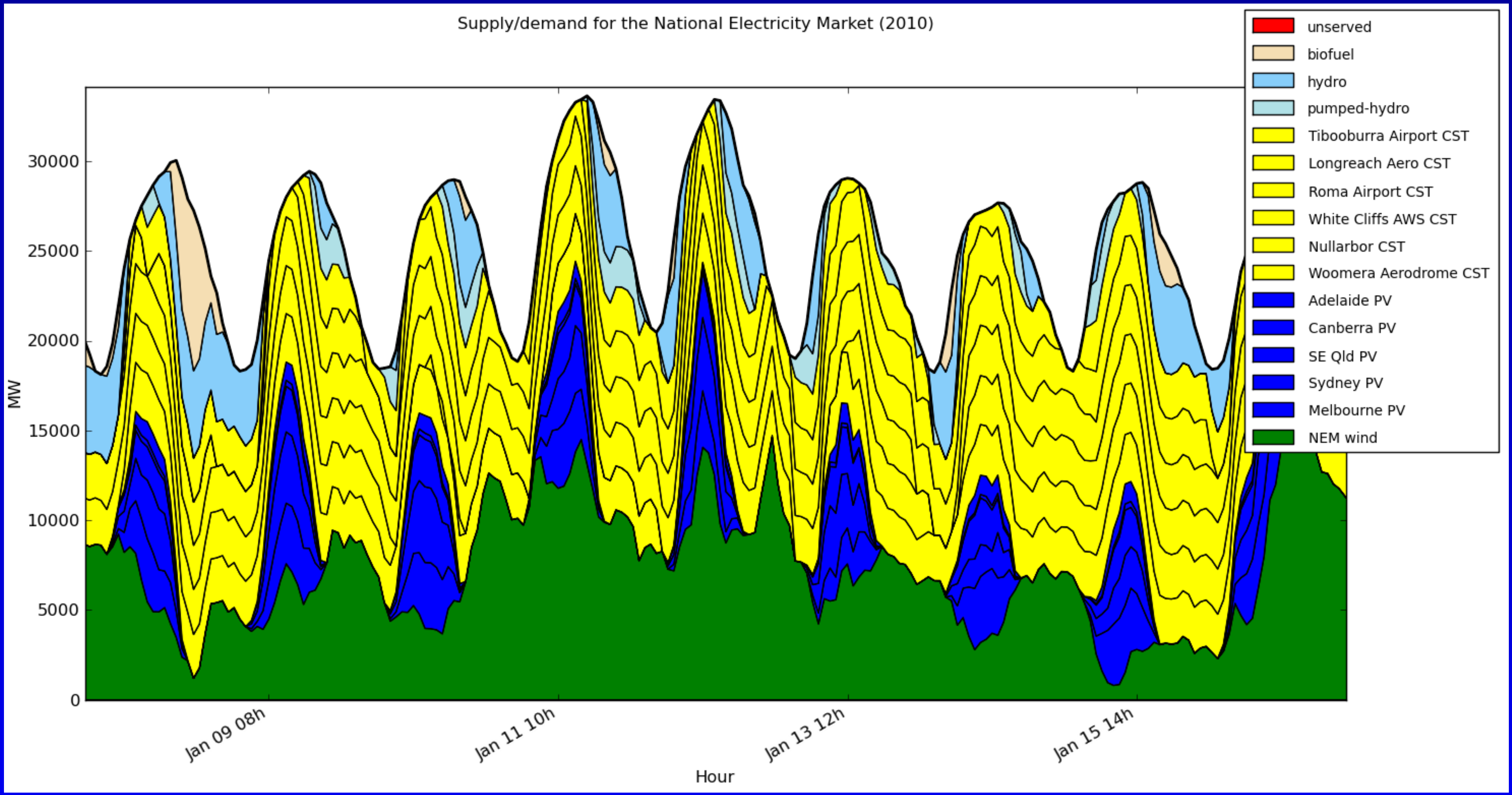
- *Simulations of Scenarios with 100% Renewable Electricity in the Australian National Electricity Market*, Energy Policy (45)
- Hourly simulations of supply to meet demand
  - Hourly NEM demand for 2010
  - Simulated dispatch using regional weather observations
- Generation mix chosen by guided exploration
  - Ensure reliability
  - No initial consideration of cost or transmission





Simulation background



Hour-by-hour plot from a week in January 2010

Simulation extensions

- Cost model
  - 2030 projected annualised capital cost ($/kW/yr)
  - Fixed O&M ($/kW/yr)
  - Variable O&M ($/MWh)
  - Optionally including transmission
  - Costs taken from AETA report (BREE, 2012)
- Regional model
  - Each “generator” assigned to a region
  - Dispatch algorithm is now region-aware
  - Tracks hourly energy exchanges between regions

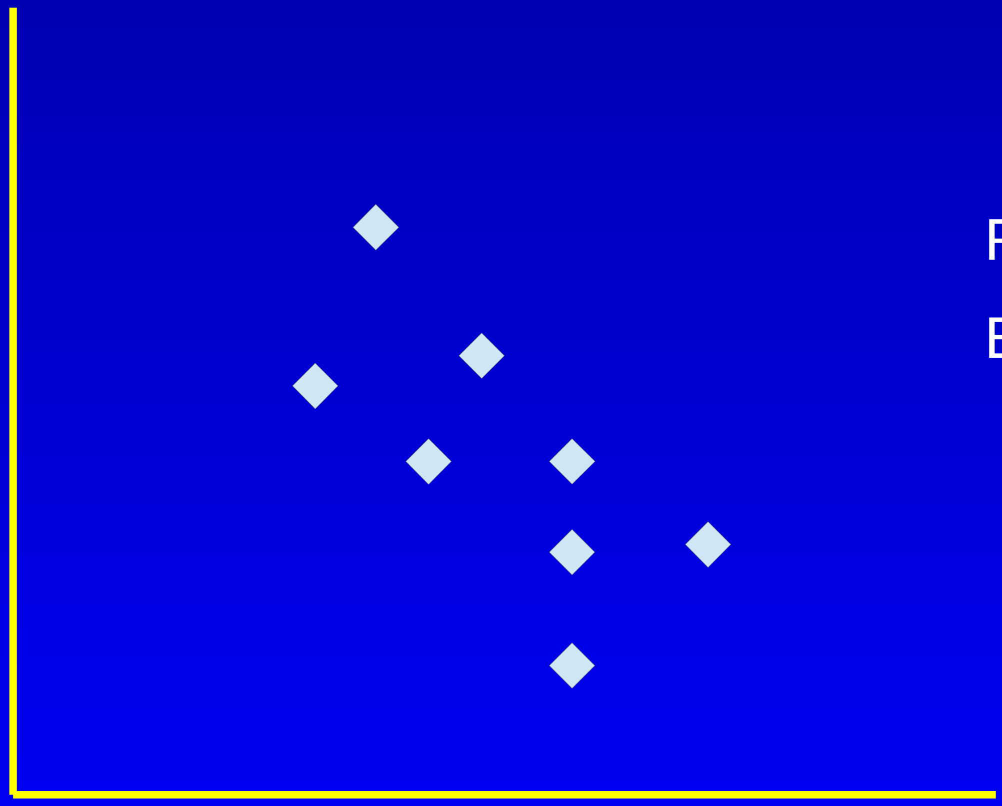
Assumed technology costs (2030)

Technology	Efficiency (GJ/MWh)	Capital cost ($/kW), **[Low – high]**	Fixed O&M ($/kW/yr)	Variable O&M ($/MWh)
Supercritical black coal	8.57	2947-3128	59	8
Supercritical brown coal	10.59	3768	71	9
Combined cycle GT	6.92	1015-1221	12	5
Open cycle GT (gas)	11.61	694-809	5	12
Open cycle GT (biofuel)	11.61	694-809	5	92
On-shore wind		1701-1917	40	14
CST (15 hours storage) †		5622-6973	65	23
PV		1482-1871	25	0

Data source: AETA, Bureau of Resources and Energy Economics (2012)
† Capital costs for CST with 15 hours storage derived from AETA data

Combining simulation and search

- Drive simulations with a genetic algorithm
- Trivial example: closest point to the origin



Generation 1 (randomly generated)

Representation: <x y>

Evaluation function: minimise

$$f(x, y) = \sqrt{x^2 + y^2}$$

Combining simulation and search

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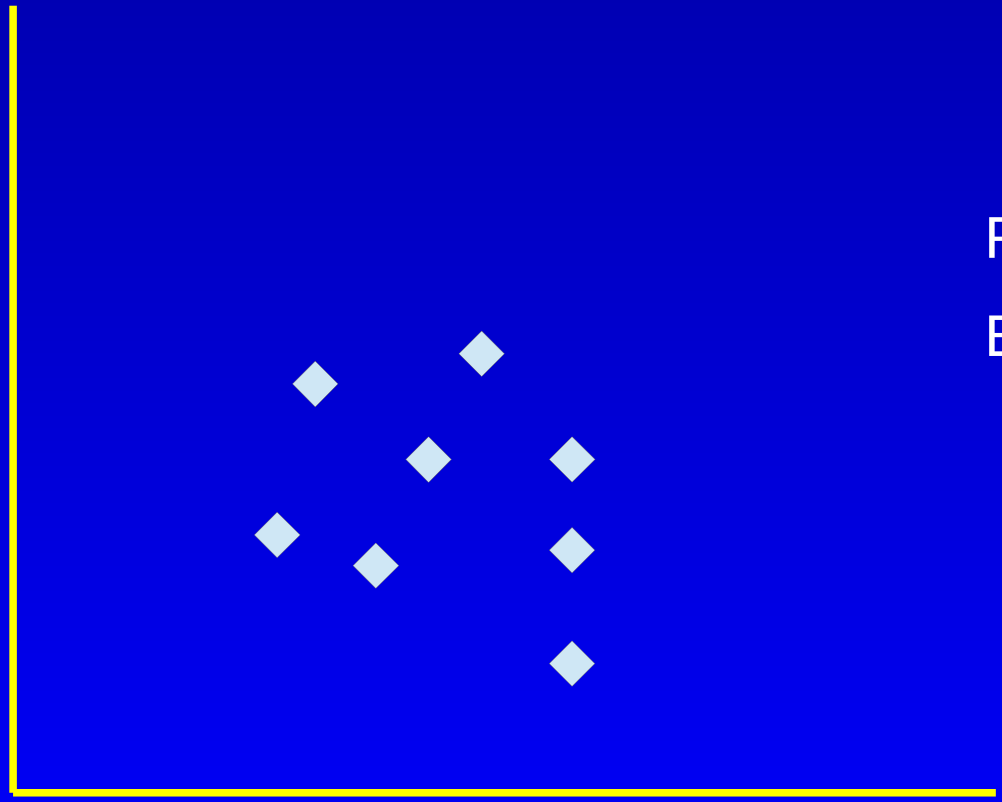


Generation 2

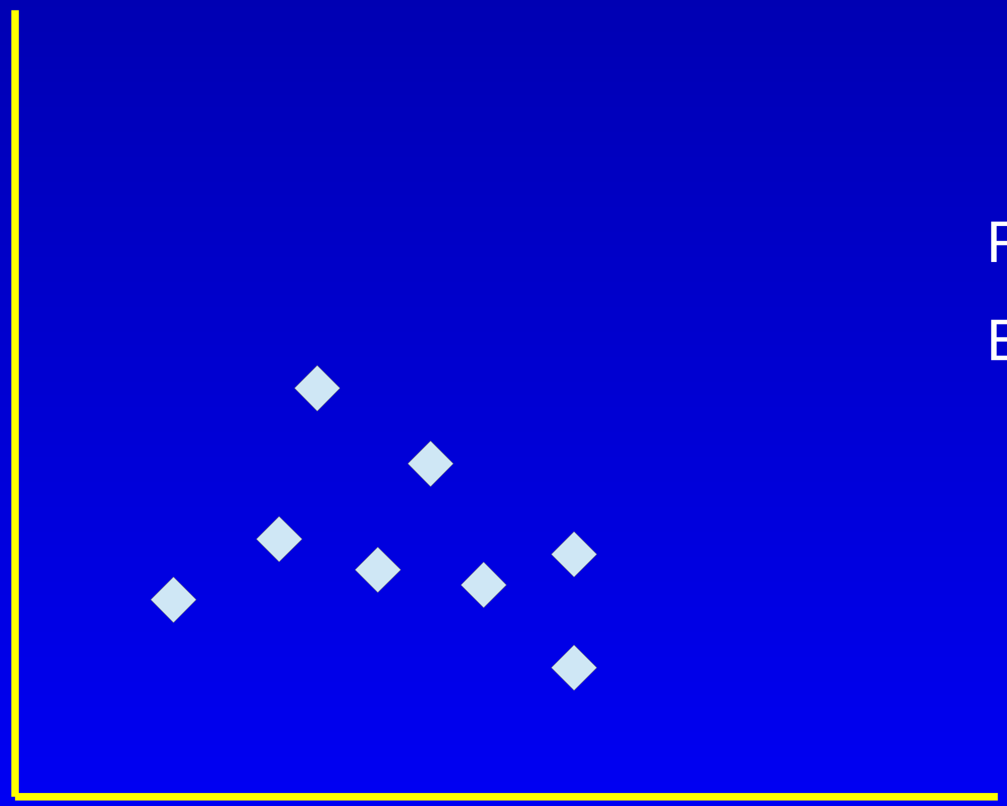
Representation: <x y>

Evaluation function: minimise

$$f(x, y) = \sqrt{x^2 + y^2}$$

Combining simulation and search

- Drive simulations with a genetic algorithm
- Trivial example: closest point to the origin



Generation 3

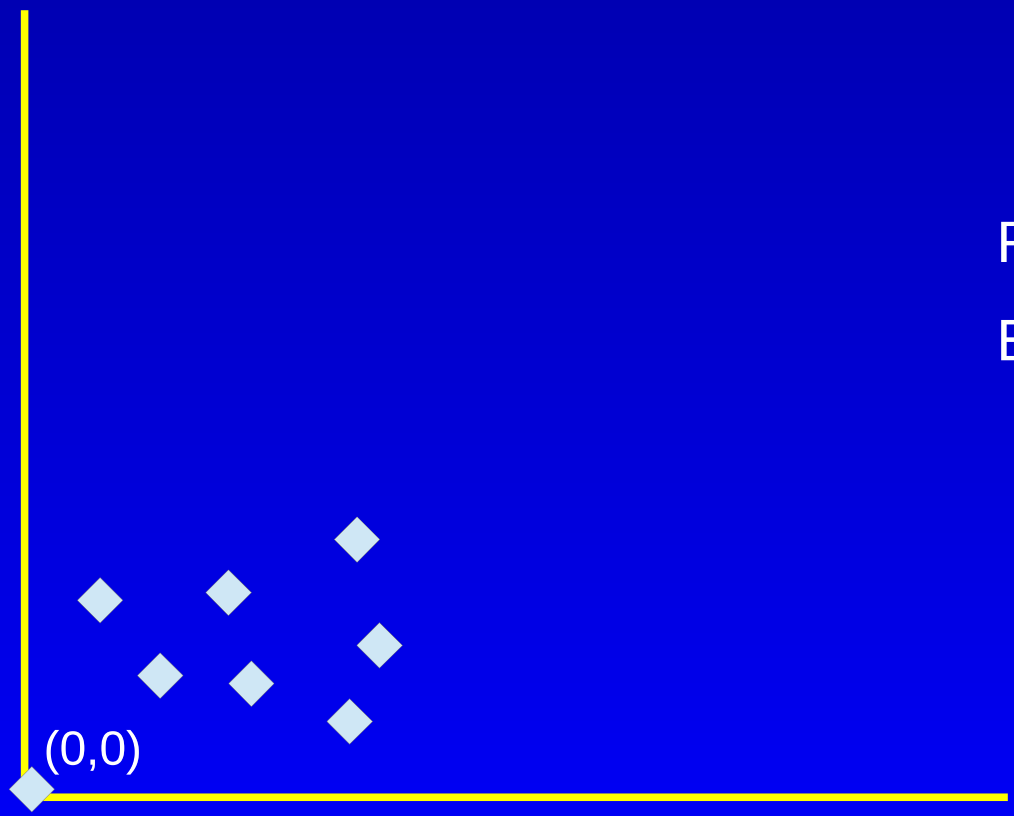
Representation: <x y>

Evaluation function: minimise

$$f(x,y)=\sqrt{x^2+y^2}$$

Combining simulation and search

- Drive simulations with a genetic algorithm
- Trivial example: closest point to the origin



Eventually ..

Representation: <x y>

Evaluation function: minimise

$$f(x,y)=\sqrt{x^2+y^2}$$

Combining simulation and search

- Drive simulations with a genetic algorithm
- GA representation
  - 25 generators in simulation
    - Some specific (eg, Woomera CST, Sydney PV)
    - Some regional (eg, Tasmanian hydro, VIC gas turbines)
  - Exclude the 5 hydro generators (fixed capacities)
  - Vector of 20 real numbers
- GA objective is to minimise annual cost
- 100 generations, population 100 = 10,000 runs

GA evaluation function

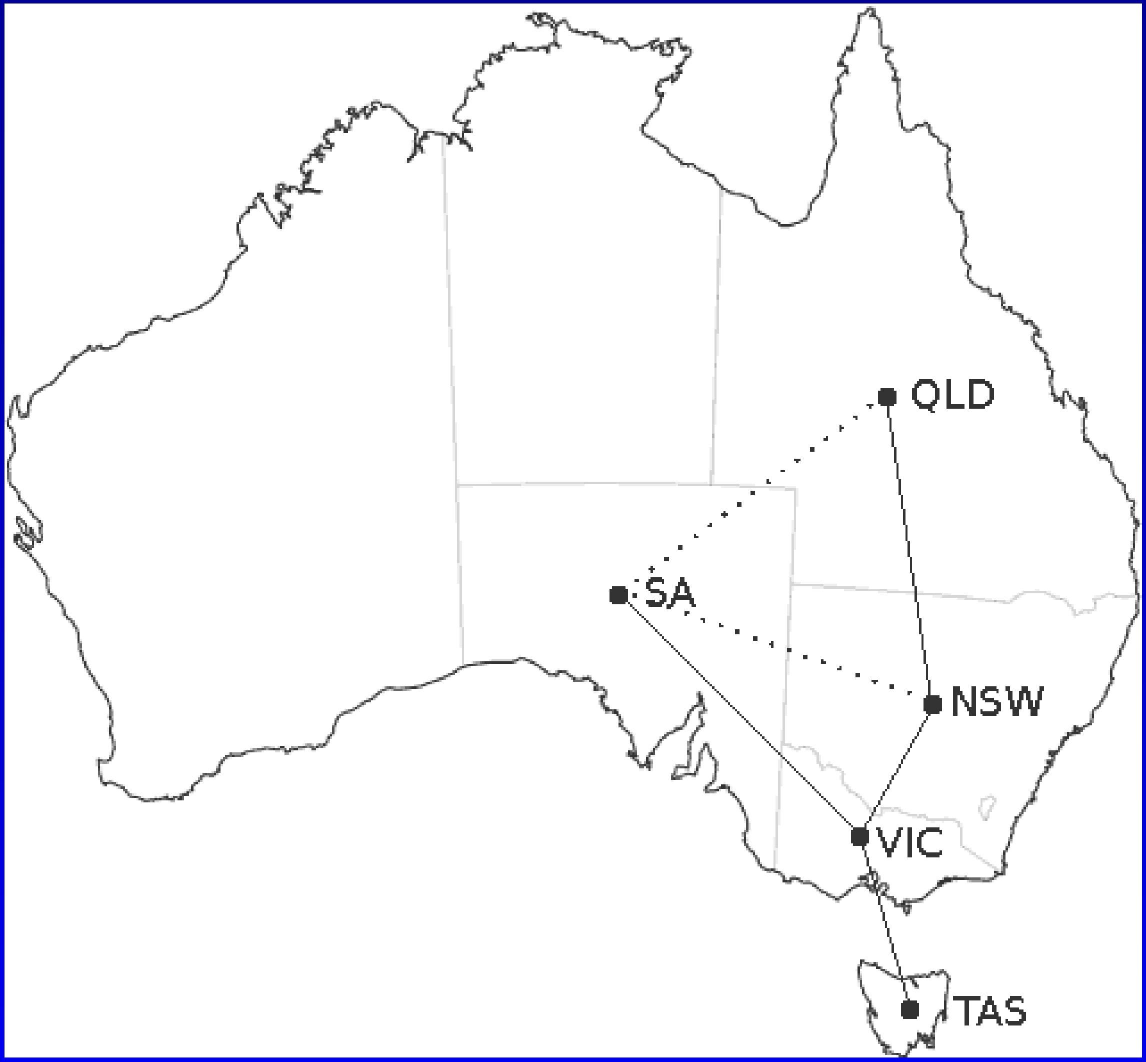
- Sum of
  - Annualised capital cost for all generators
  - Fixed O&M costs for all generators
  - Variable O&M costs for all generators
  - Penalty functions

    $f(x) = \max(0, x - D/50000)^3$ (rel. std. for demand D)

    $g(x) = \max(0, x - 20\ \mathrm{TWh})^3$ (limit bioenergy)

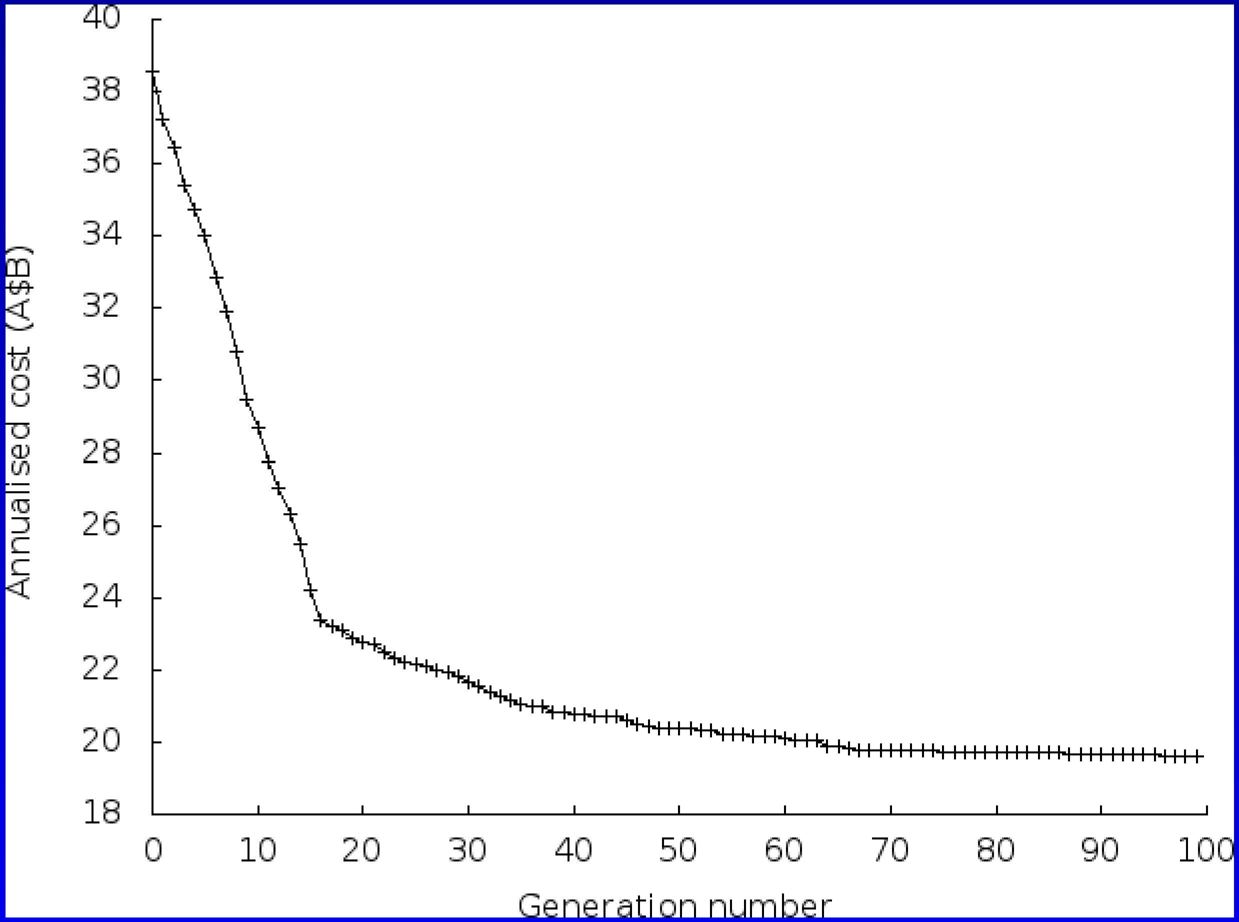
    $h(x) = \max(0, x - 12\ \mathrm{TWh})^3$ (limit hydro)
  - Optionally, costs for simplified transmission network at $800 per MW-km
- Varied by discount rate, low/high capital cost

Simplified transmission network



Regional interconnections (no capacity limit)
Dashed connections are not present today.

Progress of a single GA run



Plot showing satisfactory convergence in around 70 generations

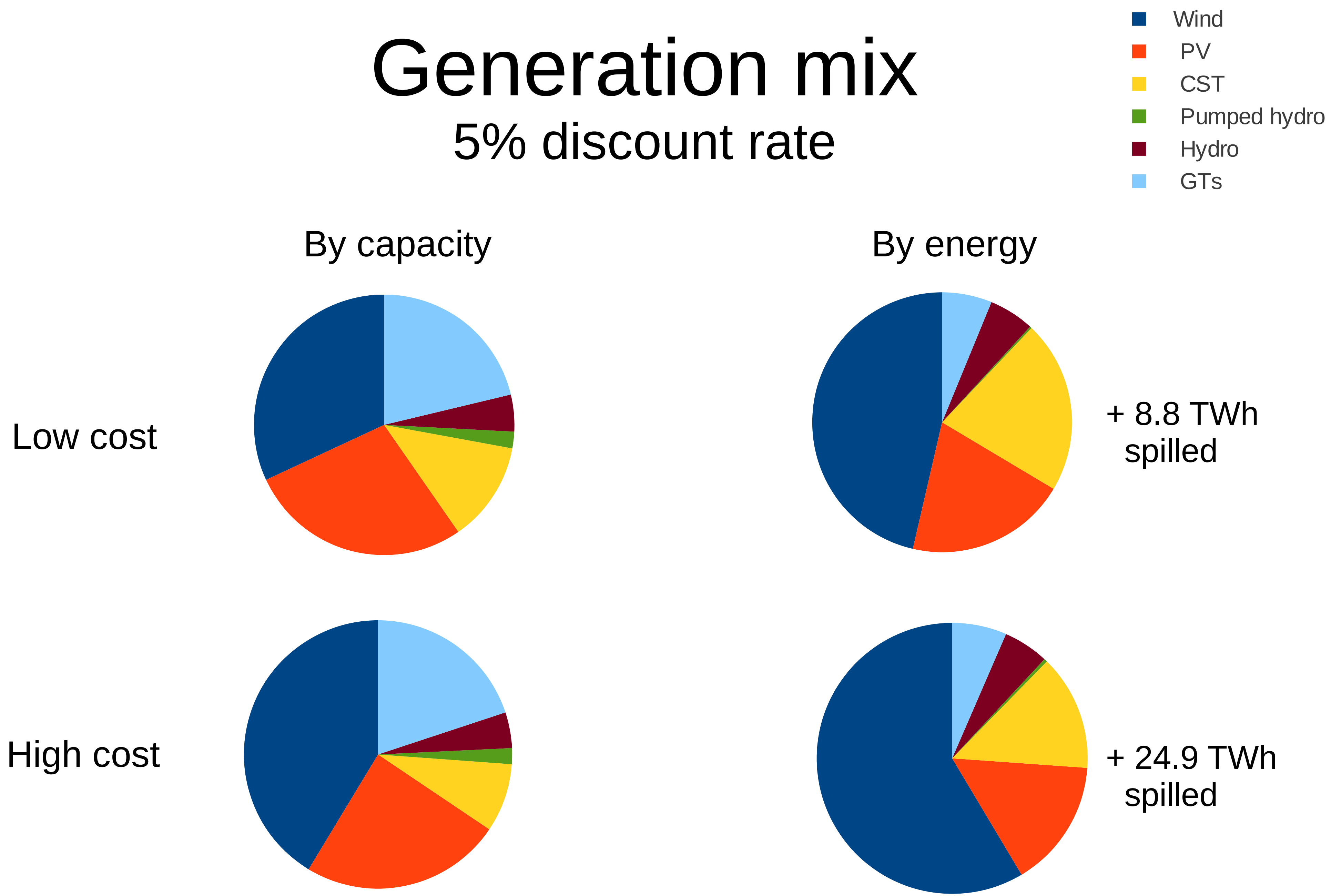
Preliminary results of least cost search

	Without transmission		With transmission	
Discount rate	Low cost	High cost	Low cost	High cost
5%	19.6	22.1	21.2	24.4
10%	27.5	31.5	31.2	35.4

Annualised cost for least cost solutions (2012 $B)

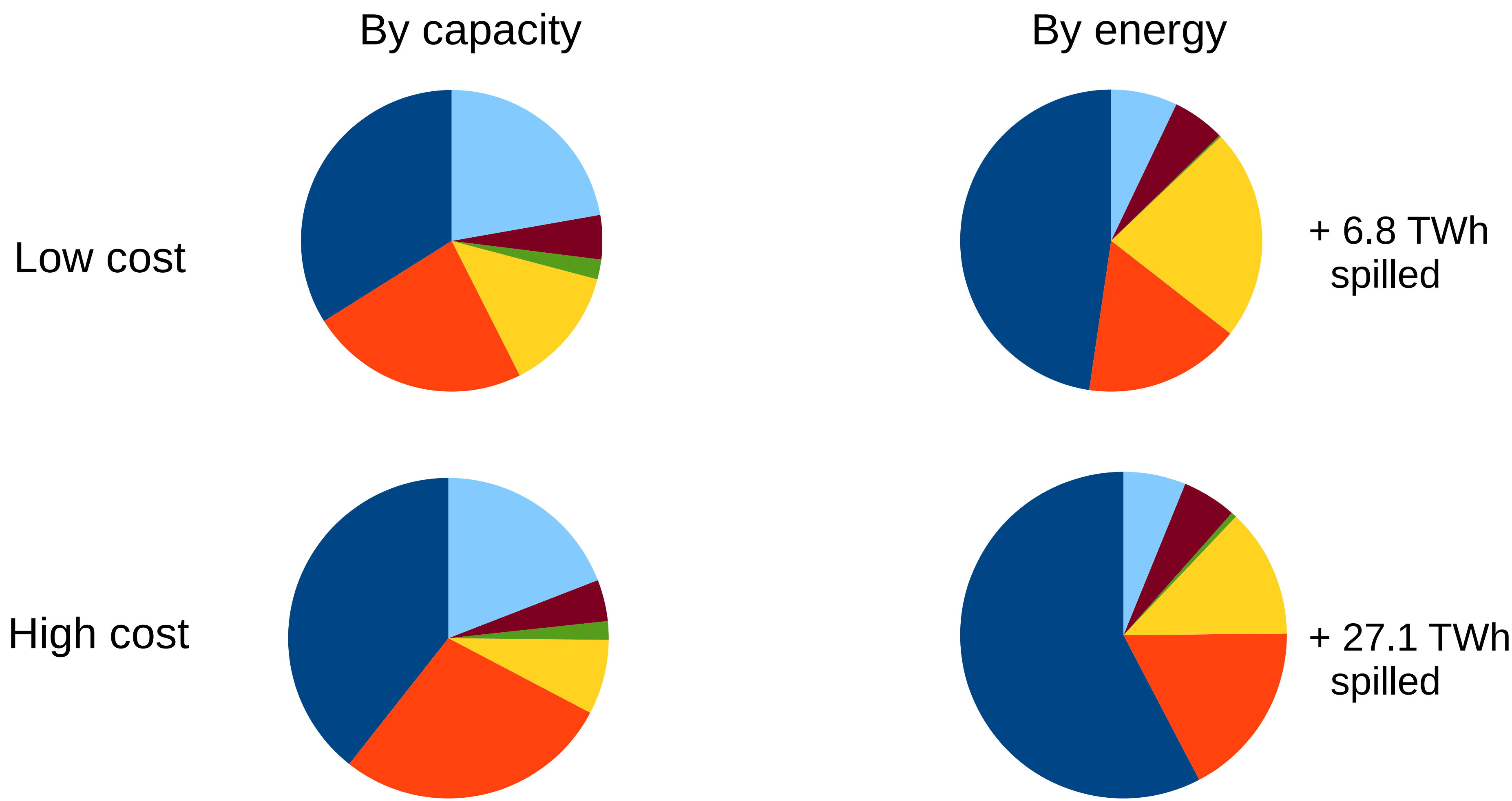
Generation mix

5% discount rate



Generation mix

10% discount rate

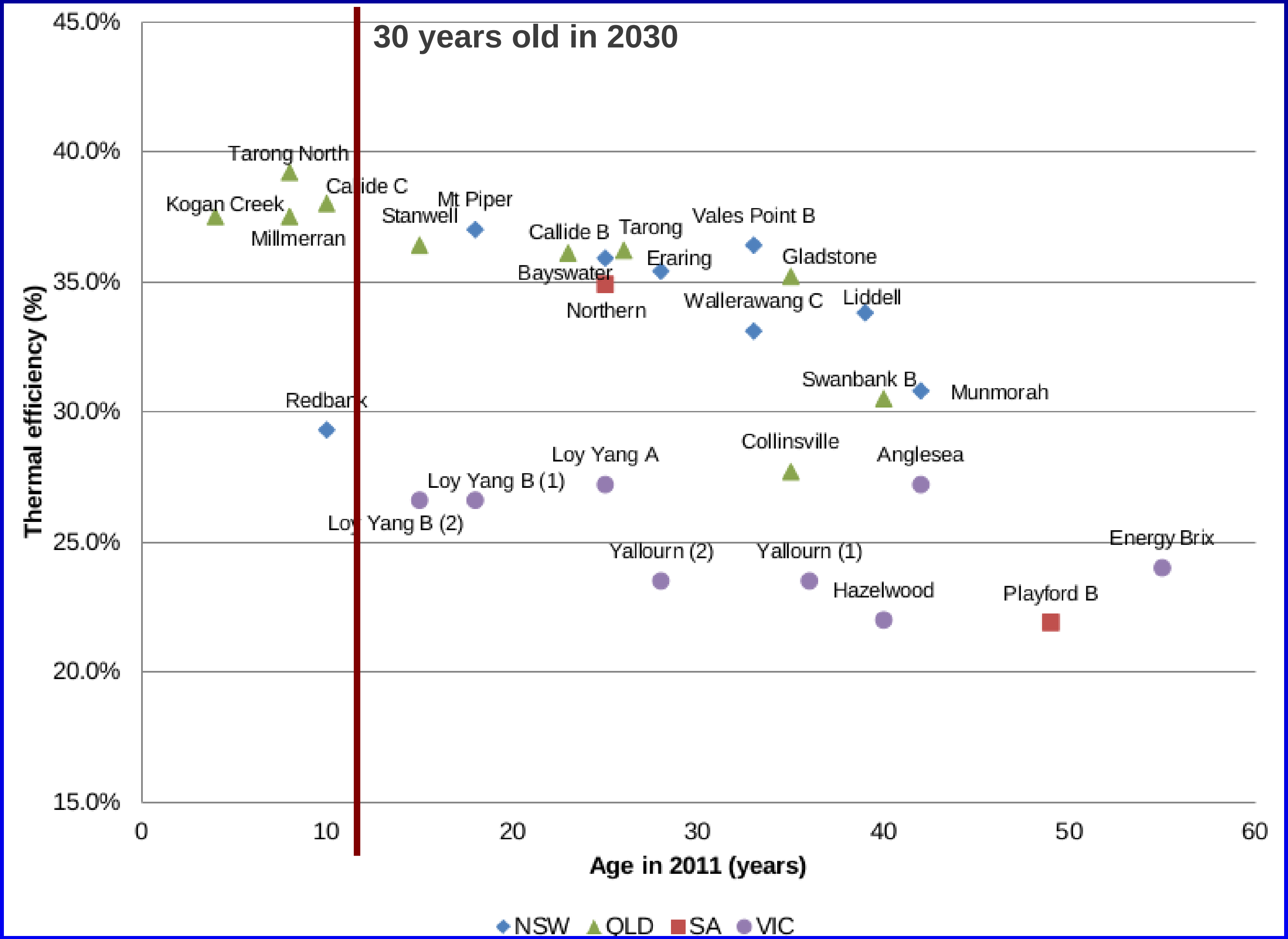


Peak energy exchanges
(when costing transmission)

	NSW	QLD	SA	TAS	VIC
NSW		8.4	4.5		9.6
QLD	8.5		3.1		
SA	7.8	8.6			4.7
TAS					2.0
VIC	10.7		6.6	1.5	

Peak energy exchanges (GWh per hour) in 2010 between NEM regions

What are we going to do?



Thermal efficiency versus plant age in the NEM (coal only). Source: Noone (2012)

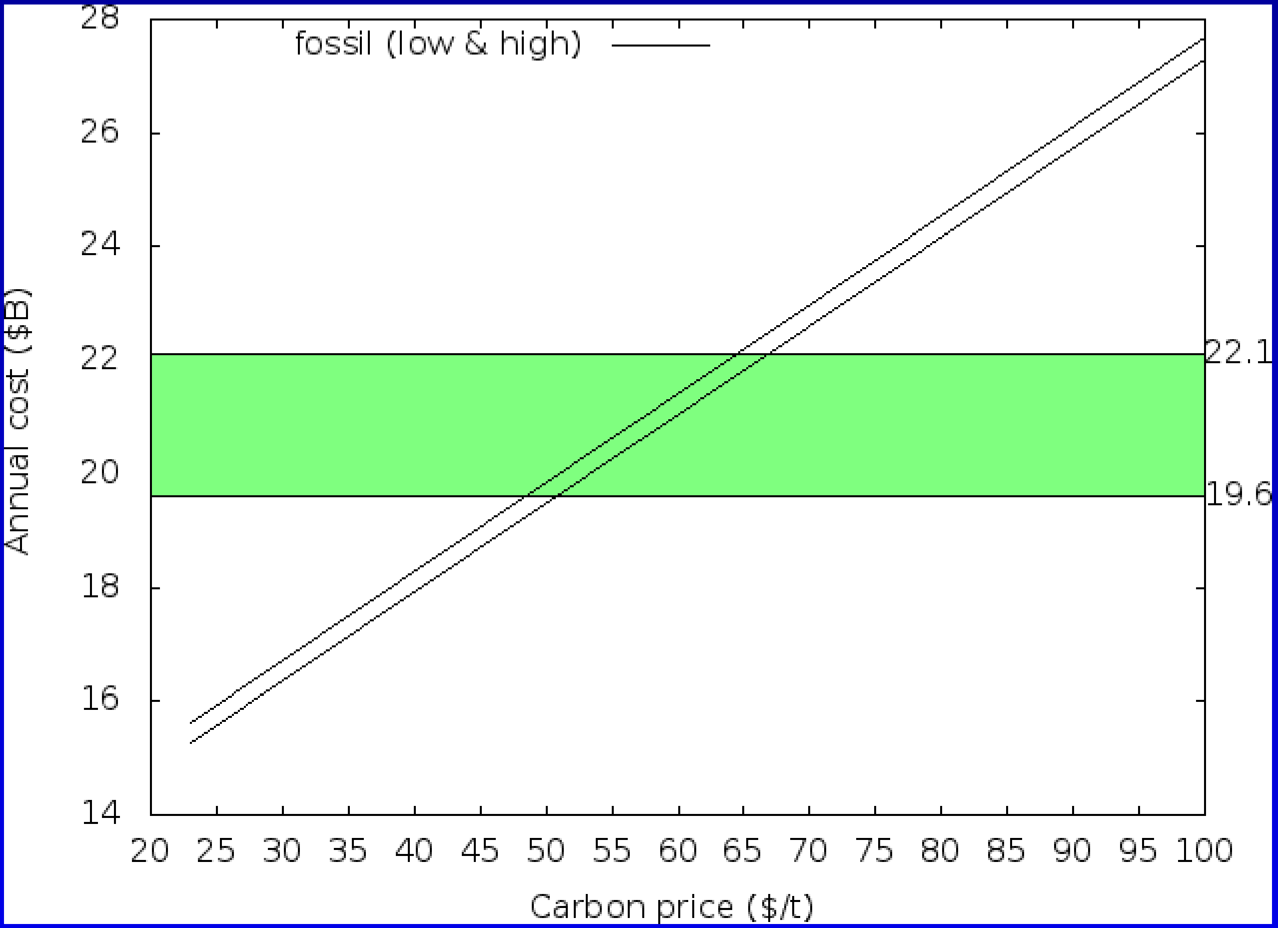
Replacement scenario

- Replace every ageing plant with a substitute
  - Direct substitute
    - eg. supercritical black coal like-for-like
  - Some upgrading
    - eg. subcritical brown coal to supercritical brown coal
  - 3 miscellaneous cases
    - eg. steam turbines fired by natural gas to CCGT
- Fuel type unchanged

Replacement scenario

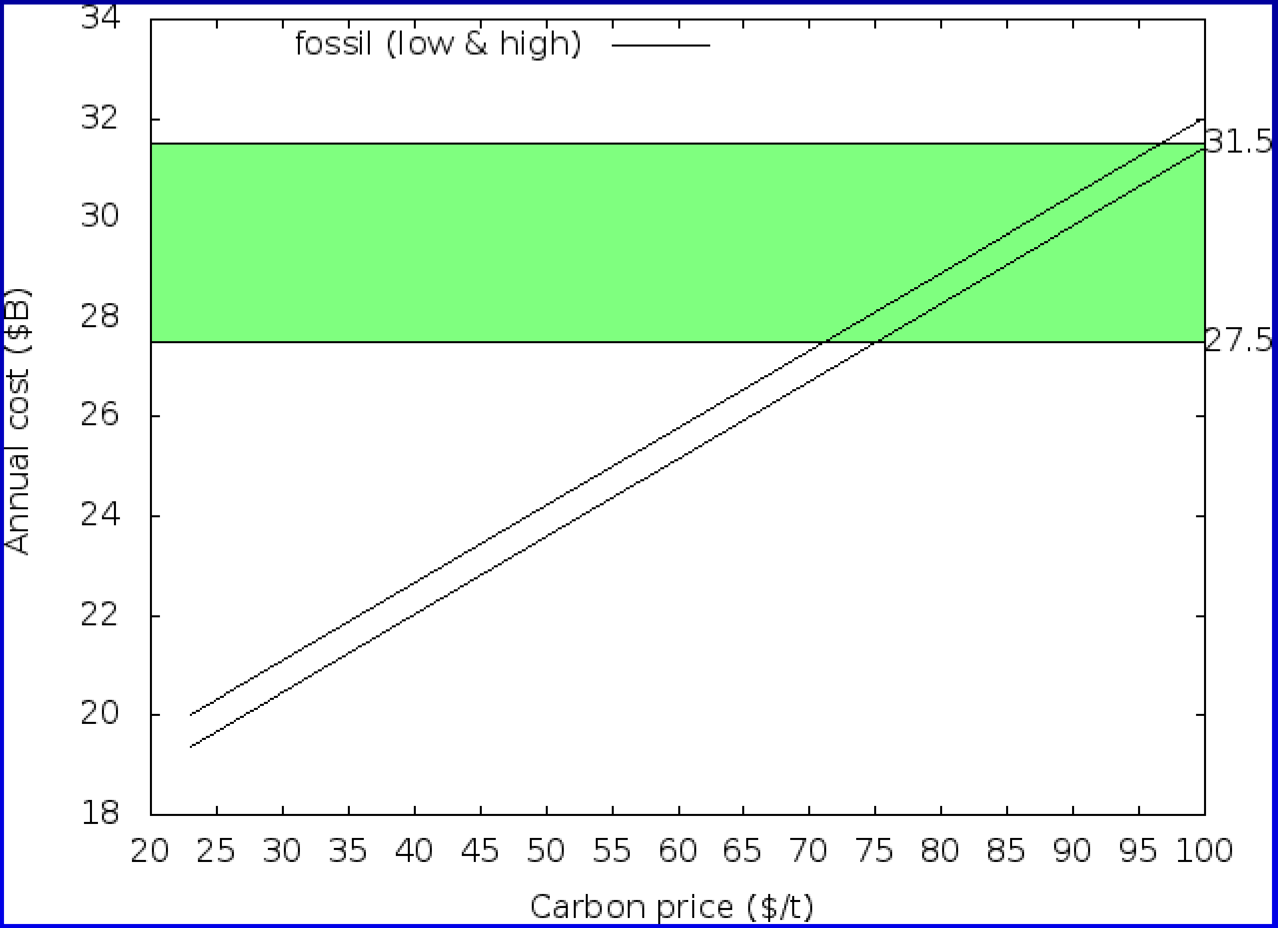
- Calculate cost to meet 2010 demand
  - Assume carbon pricing would not alter generator dispatch
  - Re-calculate SRMC for every plant
  - Calculate 2010 operating costs using dispatch data
  - Exclude plant if not dispatched in 2010
  - Price paid on all emissions
- Emissions from replacement fleet 19% lower

Comparison
5% discount rate



Plot showing the cross-over range between $50-65/tonne CO2-e

Comparison
10% discount rate

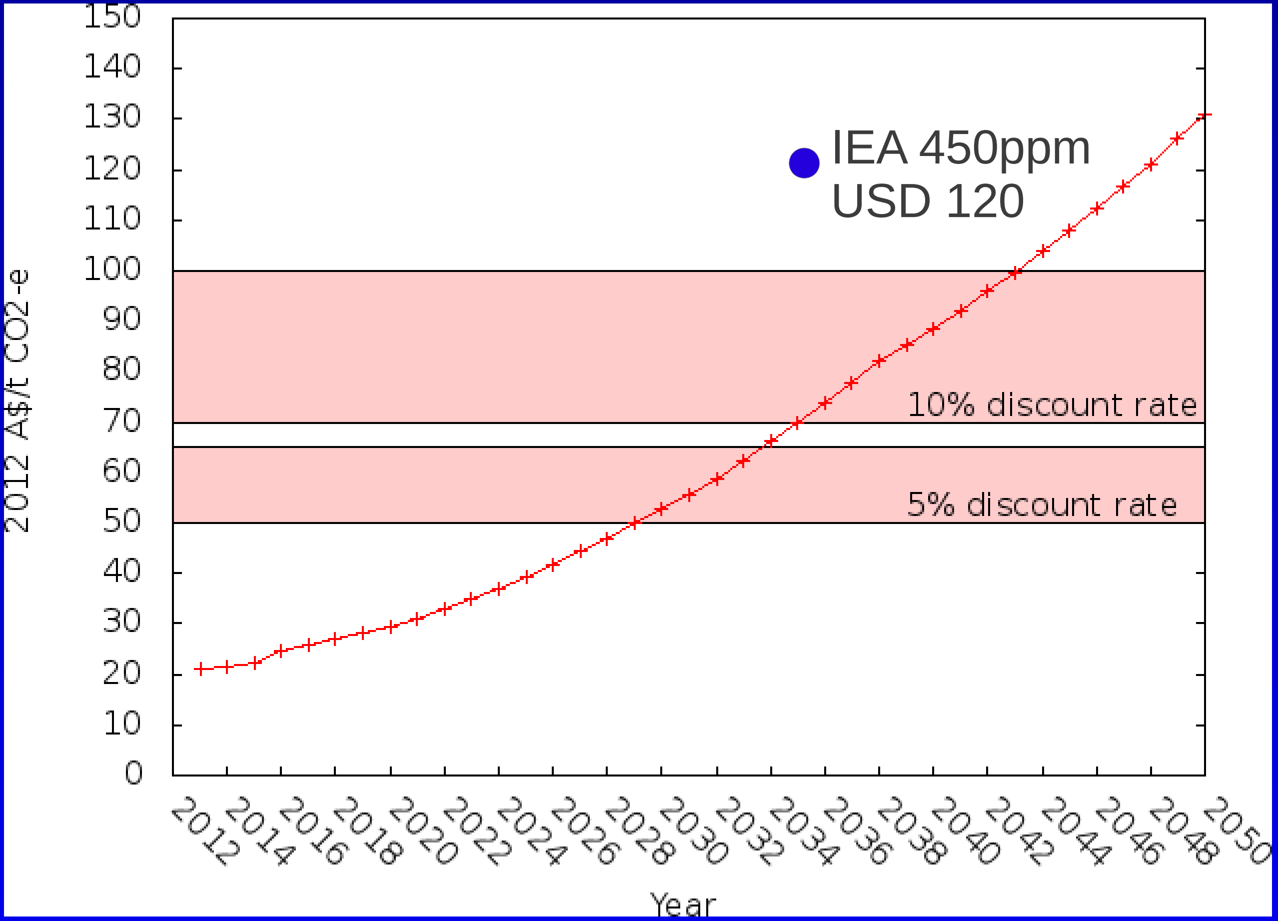


Plot showing the cross-over range between $70-100/tonne CO2-e

When could such carbon prices apply?

(SGLP, 550 ppm)

IEA 450ppm
USD 175



Modelled Australian carbon price (2012 $). Data source: Australian Treasury (2011)

Limitations and further work

- 2010 only, hourly resolution and small number of generator sites due to limited data
- Reference scenario not a likely future
- No modelling of plant or network failure
- Network model not complete, no constraints
- Further work
  - Improve temporal, spatial data resolution
  - Additional scenarios (CCS, all gas, nuclear/gas)

Conclusions

- 100% RE worthy of consideration
- Complex operational problem dependent on technologies, sites, capacities, dispatch – GAs perform well searching the problem space
- Least cost 100% scenarios dominated by wind
- CST value demonstrated in helping to meet demand, despite higher capital cost
- Cost implications of transmission modest
- At carbon prices to address CC, 100% RE is lower cost than replacement scenario