Renewables or Nuclear Electricity for Australia – the Costs

By
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Introduction

Researchers at the *Centre for Energy and Environmental Markets* (CEEM), University of NSW, did a desk study and presented a paper "*Simulations of Scenarios with 100% Renewable Electricity in the Australian National Electricity Market*" (Elliston *et al.*, 2011a) (hereafter EDM-2011).

The authors claim their study demonstrates that renewable energy could supply 100% of the Australian National Electricity Market's (NEM) electricity and meet the demand with acceptable reliability. However, they did not estimate the costs of the system they simulated.

Lang (2012) critiqued EDM-2011 and made a crude estimate of the cost of the scenario simulated and three variants of it. This paper extends that analysis by adding a fifth scenario, nuclear power, and comparing it with the four scenarios in Lang

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(2012). The four renewable energy scenarios and the nuclear scenario are compared on the basis of CO2 emissions intensity, capital cost, cost of electricity, and CO2 abatement cost (the comparisons are for the whole system).

The summary of Lang (2012) says:

> *"For the EDM-2011baseline simulation, and using costs derived from the Federal Department of Resources, Energy and Tourism (DRET, 2011b), the costs are estimated to be: $568 billion capital cost, $336/MWh cost of electricity and $290/tonne CO2 abatement cost.*
>
> *That is, the wholesale cost of electricity for the simulated system would be seven times more than now, with an abatement cost that is 13 times the starting price of the Australian carbon tax and 30 times the European carbon price. This cost of electricity does not include the costs for the existing electricity network.*
>
> *Although it ignores costings, the study is a useful contribution. It demonstrates that, even with highly optimistic assumptions, renewable energy cannot realistically provide 100% of Australia's electricity generation. Their scenario does not have sufficient capacity to meet peak winter demand, has no capacity reserve and is dependent on a technology – 'gas turbines running on biofuels' - that exist only at small scale and at high cost."*

To investigate alternative scenarios that may address the issues of reliability of supply and the high cost of these scenarios, a fifth scenario has been costed. This paper compares the results presented in (Lang 2012) with a scenario in which most of the renewable energy generation is replaced with nuclear generation.

Scenarios 1 to 4 – Renewable electricity (mostly)

Lang (2012) estimated the emissions intensity, capital cost, cost of electricity and CO2 abatement cost for the EDM-2011 baseline scenario and for three variants of it. The three variants increase the reliability of supply and reduce the cost of electricity. The four scenarios compared were:

Scenario 1 - Baseline (i.e. gas turbines running on biofuels)

Scenario 2 - Baseline with gas turbines running on natural gas

Scenario 3 - Less renewable energy + more gas to improve reliability - Scenario 2 with most pumped hydro capacity reassigned to hydro, reduced pumped hydro capacity factor, reduced capacity factor of Concentrating Solar Thermal (CST), Wind and Photo Voltaic (PV), increased natural gas capacity and capacity factor.

Scenario 4 - Reduce transmission capacity + more gas – Scenario 3 with half transmission capacity from wind farms, half transmission capacity of interstate interconnectors and reduced capacity factor of CST, PV and Wind generation because of transmission constraints.

Scenario 5 – The nuclear scenario

This paper compares the CO2 emissions and costs of a nuclear scenario with the four scenarios presented in Lang (2012). The nuclear scenario, added here, is called Scenario 5 for convenience in comparing with the four scenarios compared in Lang (2012). Figure numbers are the same as the equivalent figure in Lang (2012), but with the nuclear scenario added. In the nuclear scenario, nuclear power replaces most of the renewable energy generation capacity.

The assumptions for the nuclear scenario are:

- 20 GW of nuclear generating capacity operating at 85% capacity factor (lifetime average).
- The capital cost is from EPRI (2010), which is the same as ACIL-Tasman (2010), Table 18 (converted to 'sent out').
- O&M costs and fuel costs are as defined in EPRI (2010) and ACIL-Tasman (2010), Table 5.
- The other inputs for the LCOE analysis are the same as for fossil fuel plants given in the DRET (2010d) spreadsheet.
- Average of 100 km transmission line length to connection point to the existing transmission grid. This is probably an overestimate because some nuclear power stations would probably be built on brownfield sites – i.e. at existing coal fired power stations sites - and use the existing grid. Others may be built on the coast near the existing main grid, such as on the Gippsland coast of Victoria near the trunk 500 kV transmission lines.
- Generating capacity of hydro and pumped hydro energy storage (PHES) is the same as for Scenarios 3 and 4. Net generation from PHES is negative because no new energy is generated, but some is lost in the pumping and generation cycle.
- Generating capacity of PV is 2 GW, and wind is 5 GW because these are considered to be the minimum amount that will be implemented given existing economic and political commitments.
- Generating capacity of Open Cycle Gas Turbines (OCGT) is sufficient to provide 20% reserve capacity, excluding any capacity credit for PV and Wind. The capacity factor is set to make up the difference between the total demand of 204,400 GWh and the total generation from the other generators.

Generating capacity, capacity factor and annual generation

Figures 1, 2 and 3 compare the assumed installed generating capacity, capacity factor and annual generation for the five scenarios. The intermediate calculation results for the nuclear scenario are presented in Appendix 1 and for the other scenarios in Lang (2012).

Figure 1:

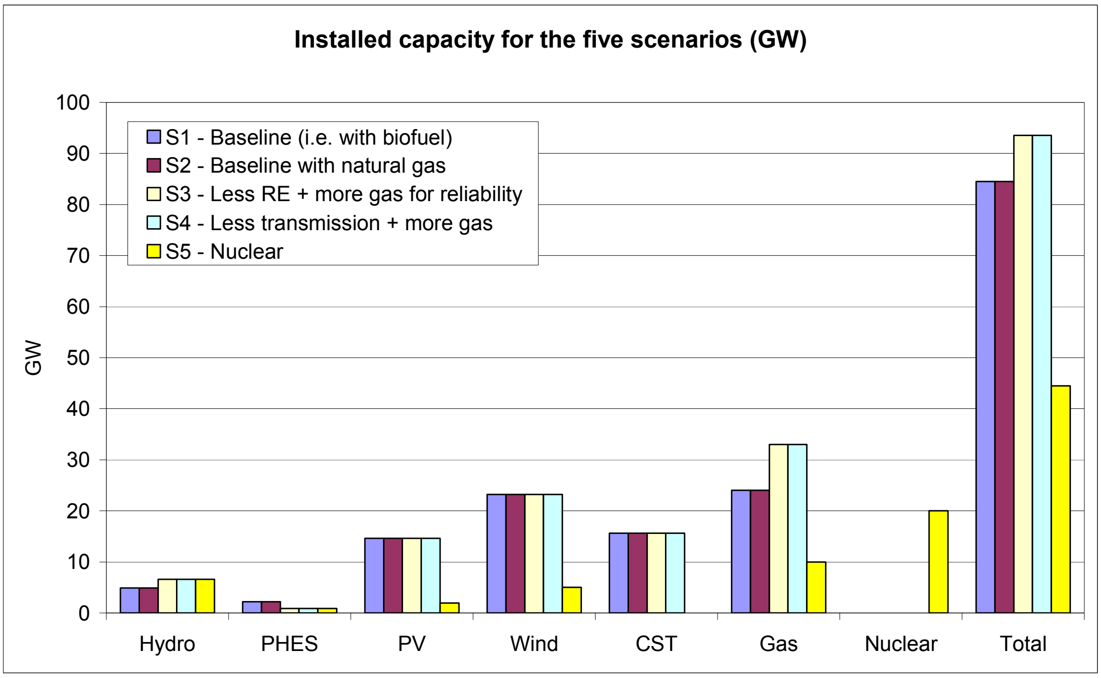


Figure 2:

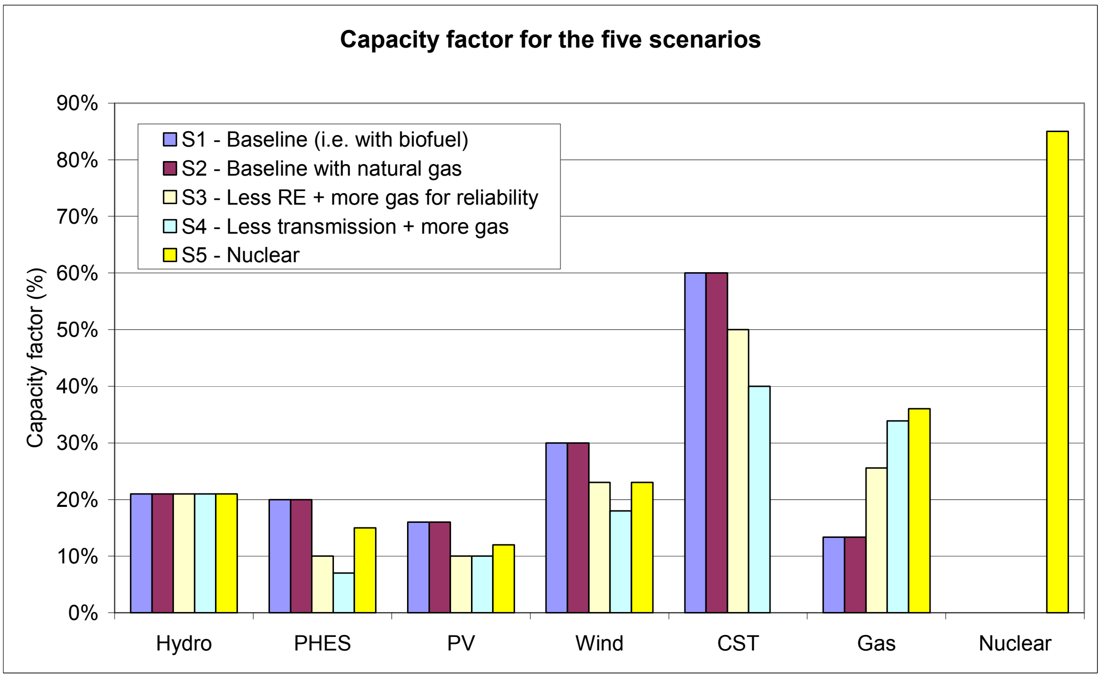


Figure 3:

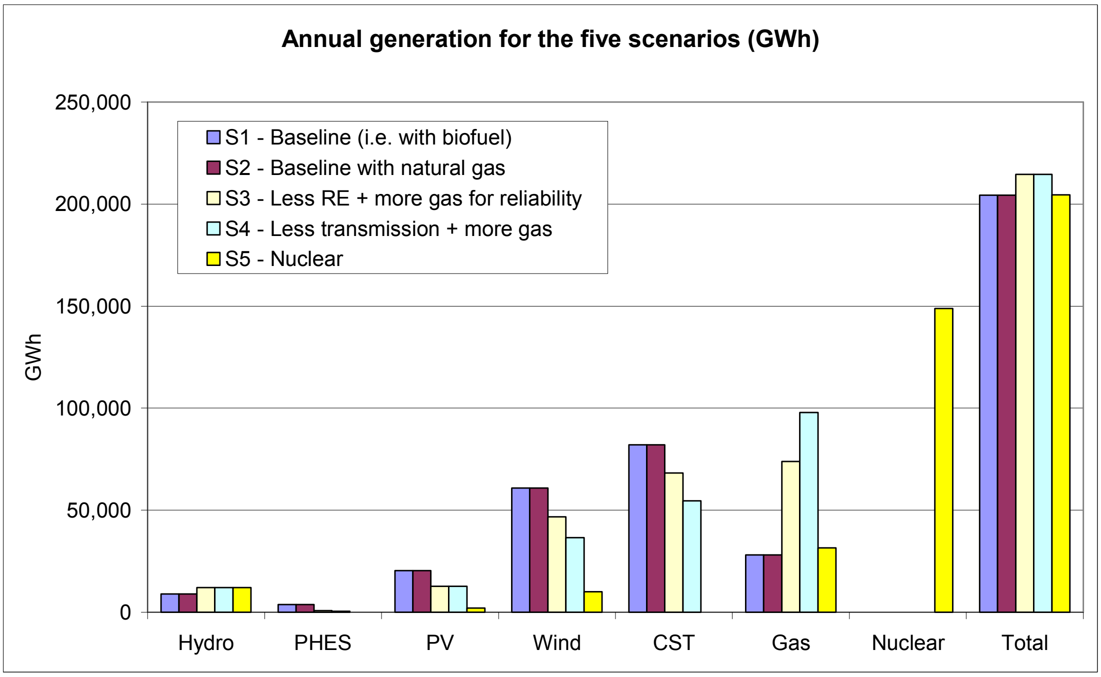
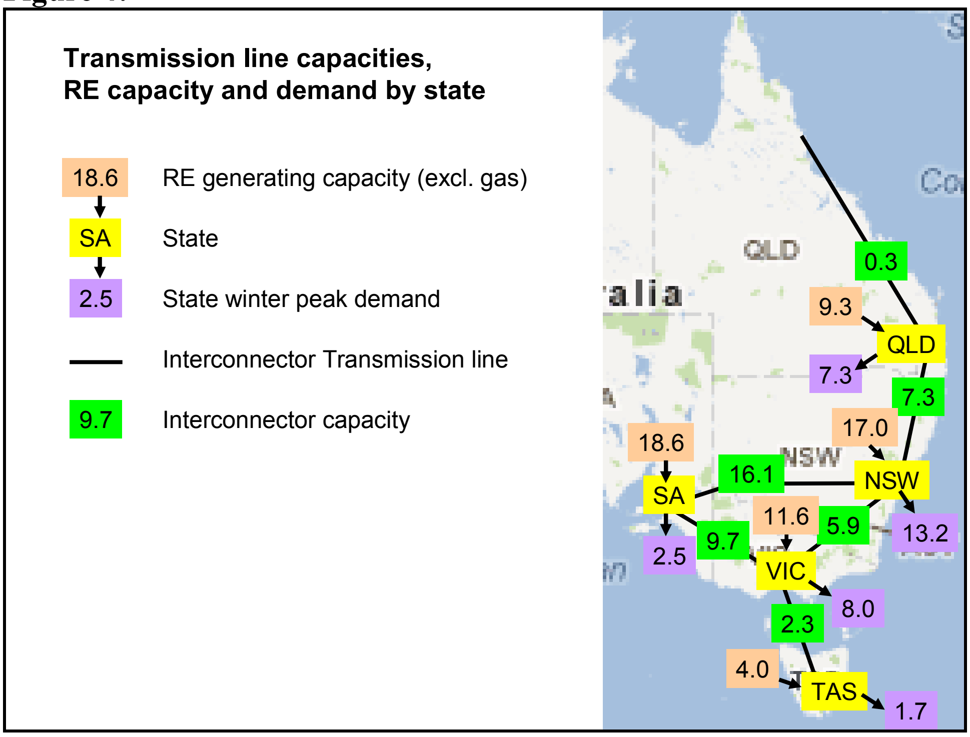


Figure 4 shows the estimated capacities for the interstate transmission lines needed for Scenarios 1 to 3, the renewable energy generating capacity (excluding biofuelled gas turbines) and the winter peak demand for each state.

Figure 4:



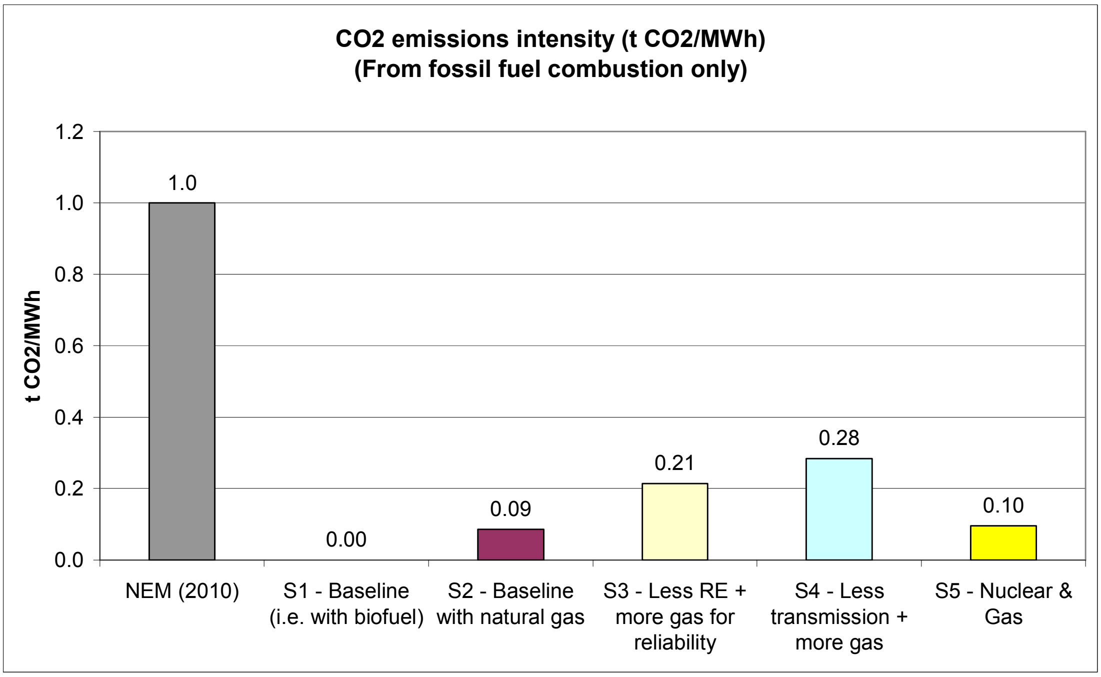
For the nuclear scenario, the existing grid is approximately adequate, so little additional transmission line capacity would be required. The cost of the nuclear scenario includes an allowance of 100 km of transmission line, with capacity equal to the generating capacity of the plant, to connect each plant to the existing grid.

CO2 emissions intensity

Figure 5 compares the CO2 emissions intensity of the five scenarios with the 2010 NEM emissions intensity (DCCEE, 2010). Appendix 1 provides calculations of CO2 emissions intensity for the nuclear scenario. The only source of emissions is natural gas generation, Scenarios 2 to5. The emissions intensity is for open cycle gas operating at their optimum efficiency; the emissions intensity is 0.622 t CO2/MWh 'sent out' (EPRI, 2010). This figure does not take into account:

a. higher emissions produced when the gas turbines are operating at less than optimum efficiency, for example during start up, shut down, spinning reserve, part load and when their power is cycling up and down to respond to changes in demand and changes in the output of the renewable energy generators. If these higher emissions were included the emissions intensity for Scenarios 2 to 5 would be higher;
b. fugitive emissions, whereas these are included for the NEM;
c. life-cycle emissions, so they do not include the emissions embodied in the power plants. .

Figure 5:



Cost estimating methodology and assumptions

The capital cost, Levelised Cost of Electricity (LCOE) and CO2 abatement cost were estimated as per Lang (2012) for Scenarios 1 to 4. The methodology is the same for the Scenario 5 (Nuclear). However, DRET (2011b), which is the source of the unit rates for Scenarios 1 to 4, does not include unit rates for nuclear. The unit rates for nuclear are sourced from EPRI (2010) and ACIL-Tasman (2010). The unit rates for nuclear were derived by EPRI (2010) on the same basis as for the other technologies so the unit costs for all five scenarios have been derived on a consistent basis. The inputs and intermediate calculation steps for the nuclear scenario are presented in Appendix 1 and, for Scenarios 1 to 4 are in Appendix 1 of Lang (2012).

All costs are in constant, 2009-10 Australian dollars. Capital costs are '*Total Plant Cost*' and do not include '*Owner's Costs'* and '*Interest During Construction'* (IDC).

Capital cost

The EPRI (2010) projected costs for new plants in 2015 were used for estimating the cost of the nuclear plant. The EPRI projected costs are for the first plant (for solar thermal and nuclear) and for the next plant of its type and size (for Wind, PV and OCGT). The projected costs for the first nuclear plant were used to calculate the cost of 20 GW of nuclear power. The average costs for 20 GW of nuclear power could be expected to be less than for the first plant. So the cost estimates for 20 GW of nuclear power are likely to be significantly overstated. This also applies for solar thermal.

As mentioned, the capital costs exclude Owner's Costs and IDC. This is common for presenting LCOE figures in Australia. The same applies for all technologies compared in all five scenarios.

Cost of electricity

LCOE for the nuclear scenario is for the projected capital cost and the operation and maintenance cost for the first 1,100 MW plant. Both capital and O&M costs could be expected to reduce significantly as more plants are built. O&M costs are as per EPRI (2010) and ACIL Tasman (2010) and fuel costs are as per EPRI (2010). The other inputs for calculating LCOE are the same as for the fossil fuel plants in DRET (2010d).

CO2 abatement costs

The CO2 abatement cost is the cost to reduce emissions intensity from the CO2 emissions intensity in the NEM in 2010 to the emissions intensity that would exist with the nuclear scenario implemented. It is expressed as 'cost per tonne CO2 abated' ($/t CO2). The LCOE and CO2 emissions intensity for the NEM in 2010 are $45.40/MWh (DRET (2011a), p22) and 1.0 t/MWh (DCCEE, 2010, Table 5, weighted average for NEM), respectively. The method of calculating CO2 abatement cost is explained in Lang (2012). The inputs and intermediate calculations for Scenario 5 are in Appendix 1.

Uncertainties in cost estimates

The greatest uncertainties in the cost estimates are in:

1. the fuel costs, capital costs and O&M costs for gas turbines running on biofuels,

2. the cost of the solar thermal plants with 15 hours of thermal storage and their lifetime average capacity factor, and

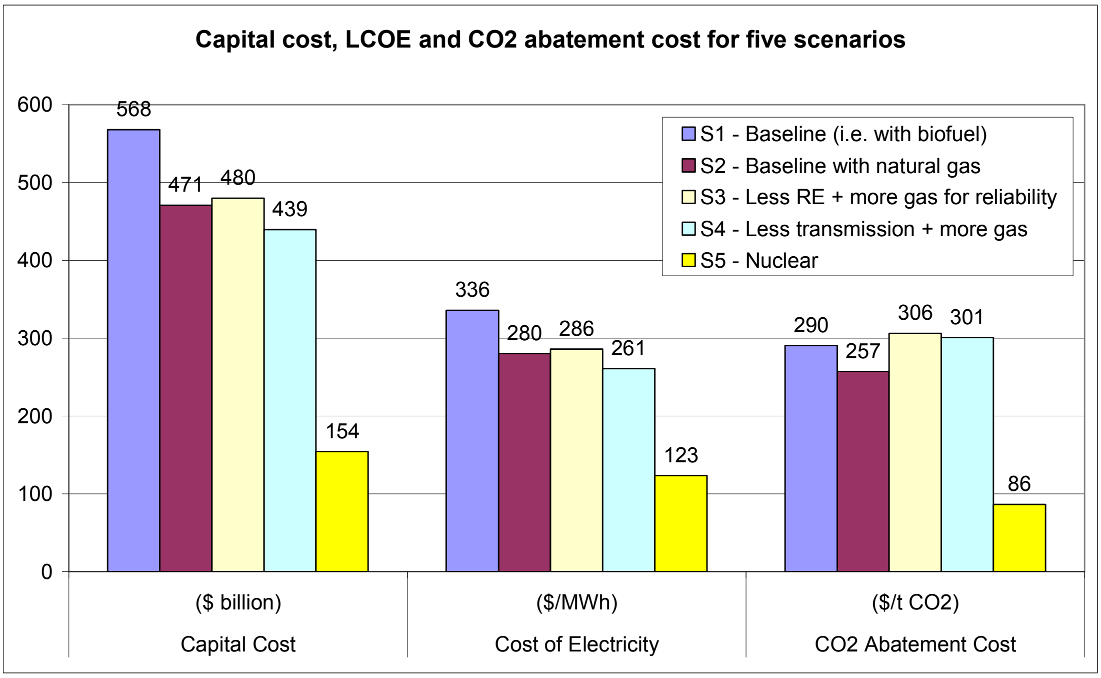
3. the amount of additional transmission and distribution capacity needed.

The uncertainties in the costs of nuclear are less than for the renewable scenarios because the nuclear technology has been proven over many decades and little additional transmission capacity is required. The uncertainties of the nuclear and renewable costs are given in EPRI (2010) and ACIL-Tasman (2010) and principally are the capital cost, with O&M cost a distant second.

Costs – comparison of five scenarios

Figure 6 compares the five scenarios on the basis of capital cost, cost of electricity and CO2 abatement cost.

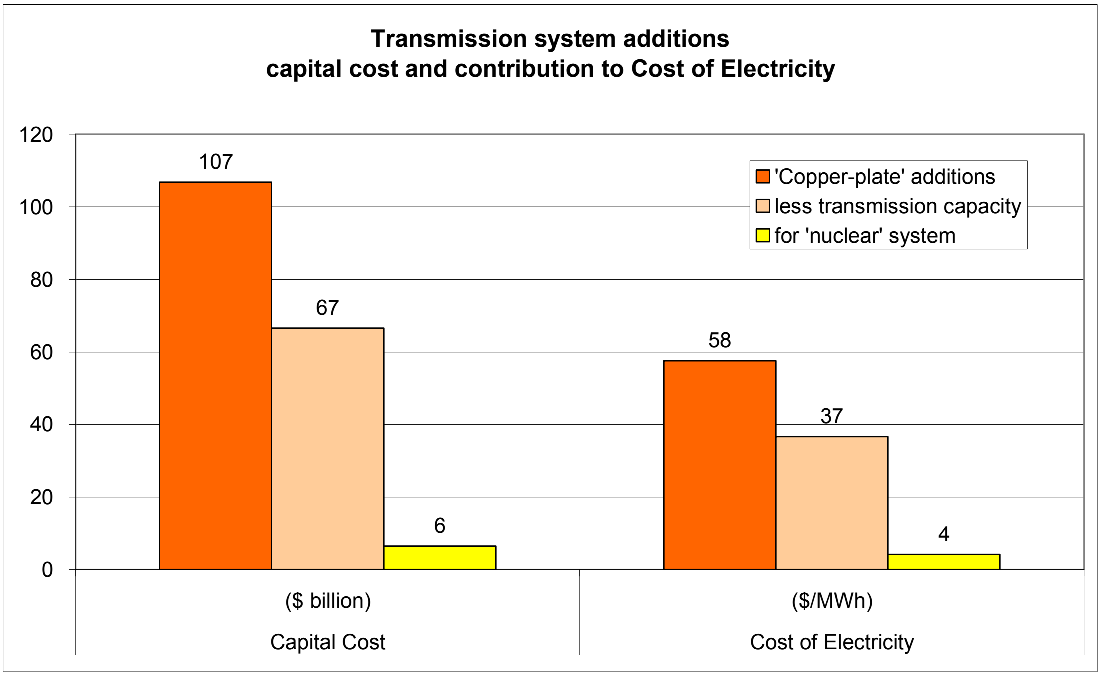
Figure 6:



Transmission is a significant component of the costs of Scenarios 1 to 4, but not of Scenario 5. Figure 7 compares the capital cost and cost of electricity for the 'copper-plate' additions to the transmission system (Scenarios 1, 2 and 3), the scenario with reduced additions to the transmission system (Scenario 4) and the nuclear scenario

(Scenario 5). The transmission cost calculations and assumptions for Scenarios 1 to 4 are presented in Lang (2012) Appendix 2, and for Scenario 5 (Nuclear) in Appendix 1 (below).

Figure 7:



Discussion

The nuclear scenario is roughly ¼ the capital cost, 1/3 the cost of electricity, and 1/3 the abatement cost of the EDM-2011 scenario, i.e. Scenario 1 - Baseline (i.e. gas turbines running on biofuels).

Furthermore, the nuclear scenario would provide a reliable electricity supply whereas the EDM-2011 scenario would not (Lang, 2012).

Of the four renewable energy scenarios considered, the fourth would provide the best reliability and least cost electricity. It's CO2 emissions are 2.8 times higher than with the nuclear scenario.

The estimated capital cost of the additions to the transmission and distribution networks, needed for the renewable energy scenarios, is $107 billion for Scenarios 1 to 3, $67 billion for Scenario 4, but just $6 billion for the nuclear scenario (Scenario 5). The cost of the additions to the transmission and distribution system for the EDM baseline scenario is nearly as much as the total capital cost of the nuclear generation component, $115 billion, of the nuclear scenario (Appendix 1, Table A1-5-2).

Conclusions

A mix of electricity generating technologies with a large component of nuclear power is the least cost way to supply low emissions electricity to reliably meet the demand for Australia's National Electricity Market.

The nuclear scenario costed here, with 73% of electricity generated by nuclear, is estimated at ¼ to 1/3 the capital cost,1/3 to1/2 the cost of electricity and about 1/3 the CO2 abatement cost of the renewable energy scenarios.

CO2 emissions from the nuclear scenario would be about 1/3 of emissions from a renewable energy system that has sufficient natural gas generation to provide a reliable power supply.

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Appendix 1 – Cost estimates for the Nuclear Scenario

Table A1-5-1: Scenario 5 - Capacity, capacity factor, generation & share

	Units	Hydro	PHES	PV	Wind	CST	OCGT	Nuclear	Total
Capacity (GW)	GW	6.6	0.9	2	5	0	10	20	**44.1**
Capacity factor		21%	15%	12%	23%	0%	36%	85%	
Annual generation	GWh	12,141	-231	2,102	10,074	0	31,536	148,920	**204,543**
Share		6%	0%	1%	5%	0%	15%	73%	**100%**

Table A1-5-2: Scenario 5, Capital Cost

	Units	Hydro	PHES	PV	Wind	CST	OCGT	Nuclear	Total
Capital cost rate	$/kW			$4,650	$2,744		$995	$5,742	
Capital Cost	$bn			$9	$14		$10	$115	**$148**
Trans additions.	$bn			$1	$2			$3	**$6**
Total capital cost	$bn			$11	$16		$10	$118	**$154**

Table A1-5-3: Scenario 5, Levelised Cost of Electricity (LCOE)

	Units	Hydro	PHES	PV	Wind	CST	OCGT	Nuclear	Total
Technology LCOE	$/MWh	$50	$300	$631	$169		$97	$117	
LCOE contribution	$/MWh	$3	$2	$6	$8		$15	$85	**$119**
Trans additions.	$/MWh			$1	$1			$2	**$4**
LCOE, gen + trans	$/MWh	$3	$2	$7	$10		$15	$87	**$123**

Table A1-5-4: Scenario 5, CO2 abatement cost

	Units	Hydro	PHES	PV	Wind	CST	OCGT	Nuclear	Total
System LCOE	$/MWh								$123
NEM 'LCOE' equiv.	$/MWh								$45
LCOE difference	$/MWh								$78
CO2 emissions factor for NEM (t/MWh)									1.0
CO2 emissions factor per technology (t/MWh)							0.622		
CO2 emissions factor for the system (t/MWh)							0.10		0.10
CO2 emissions factor difference (t/MWh)									0.90
CO2 abatement cost ($/t CO2)									**$86**