APPENDIX G: NUCLEAR POWER IN SOUTH AUSTRALIA—ANALYSIS OF VIABILITY AND ECONOMIC IMPACTS

NUCLEAR POWER IN SOUTH AUSTRALIA—ANALYSIS OF VIABILITY AND ECONOMIC IMPACTS

A combination of analyses was undertaken to determine whether nuclear energy would be viable in South Australia in the future.

A study undertaken by WSP/Parsons Brinckerhoff assessed the business case and provides quantitative analyses for developing a nuclear power plant and supporting infrastructure in South Australia.[1]

A separate study undertaken by Ernst & Young evaluated the impact of possible emissions abatement policies consistent with government policy to determine both the future energy generation mix in Australia and associated wholesale electricity prices across the National Electricity Market (NEM). Those outputs were needed to determine the market in which a nuclear power plant would operate.[2]

The outputs of both studies were used in a complementary study undertaken by DGA/Carisway which used the studies' inputs and projections of future electricity demand in South Australia in order to assess the commercial viability of both a large and small nuclear power plant operating in South Australia in 2030 or 2050.[3]

1. ANALYSIS OF VIABILITY—COMMISSIONED STUDY

ASSUMPTIONS AND INPUTS

Nuclear technology options assessed

The financial analysis initially evaluated reactor designs in the Generation III and III+ categories with a generation capacity between 700 MWe and 1600 MWe as well as small modular reactors with a generation capacity less than 300 MWe.[4]

To be further assessed, the reactor technology was required to have:

- been successfully constructed and commissioned elsewhere at least twice by 2022
- cost estimates that were able to be based on realised costs benchmarks or, if they were not available, estimates that could be independently verified.

The analysis considered the most reliable data to be recent, realised benchmarks in project development and construction time frames.

Designs from the following vendors were initially considered[5]:

- light water reactors: Westinghouse AP1000 pressurised water reactor and GE Hitachi economic simplified boiling water reactor
- pressurised heavy water reactors: Atomic Energy of Canada Limited EC6 and ACR-1000
- small modular reactors: NuScale and B&W Bechtel mPower.

The Westinghouse AP1000 reactor was assessed as being the only advanced pressurised water reactor that met the criteria of having been constructed and commissioned elsewhere at least twice before 2022.[6] This assessment was made on the basis that two units are currently under construction in the USA (Vogtle and VC Summer) and China.[7] Public reporting requirements for the costs of developing these reactors in the USA offered a robust basis for estimating the cost of such a facility in South Australia.[8]

Two boiling water reactor designs were considered. While the advanced boiling water reactor has been constructed in Japan and Taiwan, the economic simplified boiling water reactor that incorporates more passive safety features has received only design certification in the USA but is not being constructed.[9] These reactor designs were not further considered.

The EC6 pressurised heavy water reactor is a new design that has not yet been deployed anywhere in the world; the realistic potential for its deployment before 2030 is not known. The status of the advanced ACR-1000 design based on the CANDU 6 model is also not presently known. These reactor designs were not further considered.[10]

A number of small modular reactor designs are currently at various stages of design, component testing, licensing and commercial development. The two designs included for analysis of viability—NuScale and B&W Bechtel mPower—have received substantial funding from the US Department of Energy and are close to having design submissions that are ready to be reviewed by the US Nuclear Regulatory Commission.[11]

While sufficient design and test work has shown that the design of these reactors is likely to be technically feasible, the extent to which efficiency in factory assembly-line type fabrication will overcome the economies of scale offered by a large nuclear power plant is uncertain.[12]

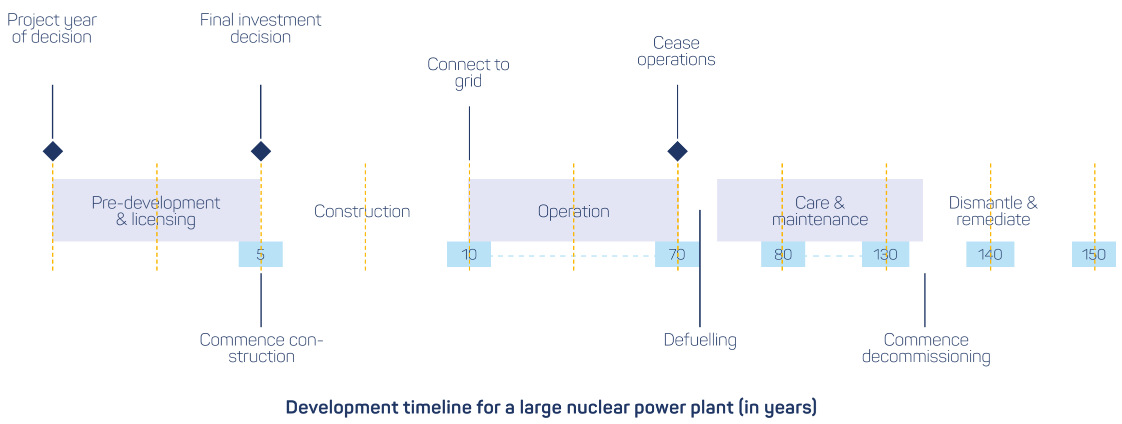


Figure G.1: Development timeline for a large nuclear power plant

Source: WSP/Parsons Brinckerhoff

NON-NUCLEAR OPTIONS ASSESSED

The study also analysed separately two non-nuclear energy generation options that could be operated as part of a low-carbon energy generation system with intermittent renewable technologies. It assessed the viability of installing a commercially proven combined cycle gas turbine system. As an alternative, the gas turbine system was modelled with the unproven carbon capture and storage technology. That analysis provided a baseline against which the viability of nuclear could be measured.

TIMELINE FOR CONSTRUCTION AND OPERATION IN AUSTRALIA

Using the development time frame for a large nuclear power plant in the USA as a basis, an approximate timeline for the development of a large nuclear power plant is presented in Figure G.1.[13] It shows a projected total time frame of approximately 10 years for pre-construction activities including project development, regulatory approval, and licensing and facility construction.

The analysis assumed that project development and licensing time frames for a small modular reactor would be the same as that for a pressurised water reactor. It assumed a short construction time frame of three years on the basis of the pre-fabricated design of small modular reactors.

SITING

Due to costs associated with construction being affected by the presence of existing infrastructure, the viability analysis was undertaken siting the plants on both greenfield or brownfield sites.

A brownfield site was assumed to be very close to or adjacent to established road and electricity transmission infrastructure. A greenfield site, on the other hand, was assumed to be located 50 km from existing supporting infrastructure. For both siting scenarios, a wharf facility was assumed to be developed to support the construction of these facilities and to enable fuel to be transported to and from the nuclear power plant.[14]

CAPITAL AND OPERATING COSTS

Capital cost estimates for the large nuclear power plant were based on realised costs for the Westinghouse AP1000 projects in the USA.[15]

For small modular reactors, cost estimates were based on those of a large scale PWR, with an additional 5 per cent to take account of the absence of benchmark costs.[16]

For both large and small nuclear plants, supporting infrastructure cost estimates were based on realised costs for roads, electrical network infrastructure and wharf facilities in South Australia.[17]

The capital operating and used fuel management costs estimated for the Commission are presented in Table G.1.

For the non-nuclear generating technologies used as a comparison, the capital and operating cost estimates for a combined cycle gas turbine system were drawn from studies published by the Australian Energy Technology Assessment and the Electric Power Research Institute study for the Carbon Dioxide Cooperative Research Centre (CDCRC).

The analysis used the gas price forecast produced for the Australian Energy Market Operator by Acil Allen in December 2014. On this basis, it was assumed that gas prices would vary marginally in the range $9.20–$10.20 per gigajoule between 2030 and 2050.[18]

Table G.1: Life cycle capital and operating costs for two types of small modular reactor and a large nuclear reactor at brownfield and greenfield sites

A$ 2014	Small modular reactor (360 MWe capacity)	Small modular reactor (285 MWe capacity)	Large nuclear reactor (pressurised water reactor – 1125 MWe capacity)
Brownfield site	$3302m ($9173/kW)	$2942m ($10 323/kW)	$8962m ($7966/kW)
Greenfield site	$3692m ($10 256/kW)	$3331m ($11 689/kW)	$9323m ($8287/kW)
Non-fuel operating costs	$61m	$48m	$190m
Fuel costs	$11.80/MWh	$11.80/MWh	$9.90/MWh
Used fuel disposal cost	$5.80/MWh	$5.80/MWh	$4.90/MWh

Source: WSP/Parsons Brinckerhoff
Notes: m = million, MWe = megawatt electrical, MWh = megawatt hour

Table G.2: Assumed level of CO_2-e emissions reduction and corresponding policy mechanisms

Scenario	Current policies	New carbon price	Strong carbon price
Assumed level of emissions reduction	2030: 26–28% reduction in CO_2-e emissions relative to 2005 levels 2050: 80% reduction in CO_2-e emissions relative to 2005 levels		2030: 65% reduction in CO_2-e emissions relative to 2005 levels 2050: complete decarbonisation
Economic policy	Expansion of emissions reduction fund to 2030 Carbon price implemented beyond 2030	Carbon price policy implemented over the period 2017–2050	Carbon price policy implemented over the period 2017–2050

Source: Ernst & Young

FUTURE TECHNOLOGY MIX

An assessment was undertaken to determine the likely future combination of energy generation technologies comprising solar photovoltaic (PV) and wind generation (both with and without energy storage), battery vehicle to grid with electrical vehicle storage, and open cycle gas turbines.[19] This was analysed as being affected by both abatement policies and the costs of those technologies.

EMISSIONS ABATEMENT POLICY

Three scenarios were developed to reflect a range of realistic and possible emissions abatement targets and policies: see Table G.2. The future carbon price to which each of those policies correspond can be seen in Figure G.2.

FUTURE ENERGY GENERATION COSTS

This analysis required an assessment of the impact of the future costs for renewable energy generation and storage technologies, as well as fossil-fuelled generation and carbon capture and storage.

The analysis relied on the estimates of costs from the Australian power generation technology report (2015)[20], to determine which technologies would be able to offer the lowest overall wholesale electricity prices to meet expected demand in 2030. It took account of expected reductions in cost previously published as part of the Australian Energy Technology Assessment 2013 update, as shown in Figure G.3. The cost reductions in those assessments favour new technologies over mature ones, and assume significant reductions in the cost of wind, solar PV, and carbon capture and storage compared to nuclear and fossil fuel generators.

The costs for nuclear were based on the analysis developed above, but excluding project development and licensing costs. This ensured a consistent comparison with the other technologies in the market model. The costs for nuclear are shown with the costs for other technologies in Figure G.3.[21]

The analysis of profitability, however, included project development and licensing costs.

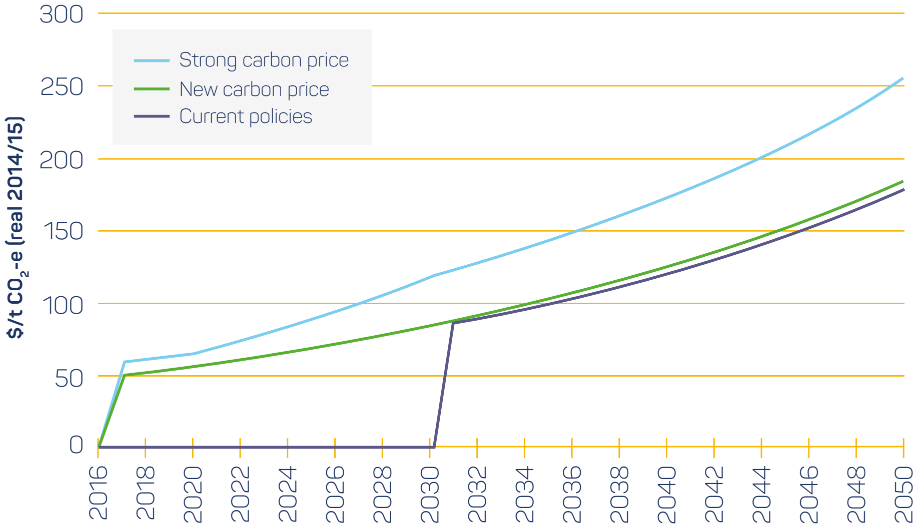


Figure G.2: Assumed carbon prices under the Current Policies, New Carbon Price and Strong Carbon Price scenarios

Source: Ernst & Young

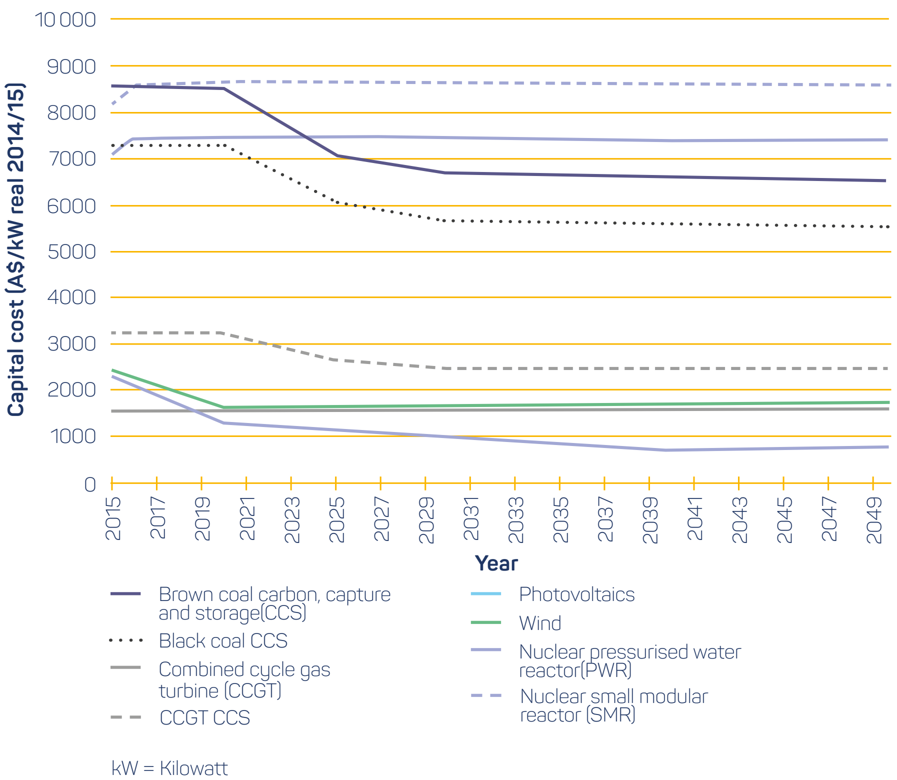


Figure G.3: Estimated capital costs of key technologies to 2050

Source: Ernst & Young

DEMAND

The analysis of demand required views to be reached about the extent to which residential customers would deploy rooftop solar PV and storage technologies and adopt electric vehicles in the future, as each of these affects network demand. However, no independent assessment was made on the returns to the households making those investments. The analysis assumed:

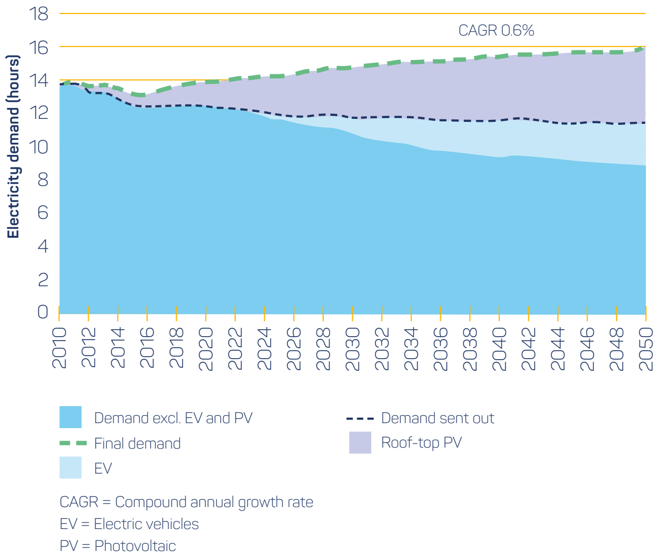
- that saturation capacity for solar PV (75 per cent of suitable dwellings would have installed capacities of 3.5 kW each) would be reached in South Australia by 2028.[22]
- the substantial uptake of storage technologies by half of all households with solar PV systems would lead to battery storage totalling 1.75 GWh by 2030. This is consistent with the assessments of the CSIRO's Future Grid Forum report[23] and a separate 2015 CSIRO assessment of future energy storage trends for the Australian Energy Market Commission[24] on the basis that the costs of these systems would halve by 2030.[25]
- a higher rate of uptake of electric vehicles under the strong carbon price scenario and a lower rate of uptake under the new carbon price scenario that were consistent with those made by ClimateWorks and Future Grid Forum analyses respectively.[26]

A sensitivity study presented in Figure G.4 outlines the effect of these assumptions being different.

The potential for meeting demand from other regions of the NEM was addressed. For the scenarios that included nuclear generation, an interconnector capacity of 2000 MWe was assumed. However, these analyses did not assess the potential viability of undertaking upgrades to the capacity of connection between South Australia and the eastern regions of the NEM because that would require a detailed regulatory investment test to assess net benefits to electricity consumers in different regions of the NEM.[27]

Electricity demand across Australia was estimated using the general equilibrium modelling analysis for the entire Australian economy, which takes into account the wider economic impacts of implementing emissions abatement policies.

The outcomes of these analyses on demand are shown in Figure G.4.



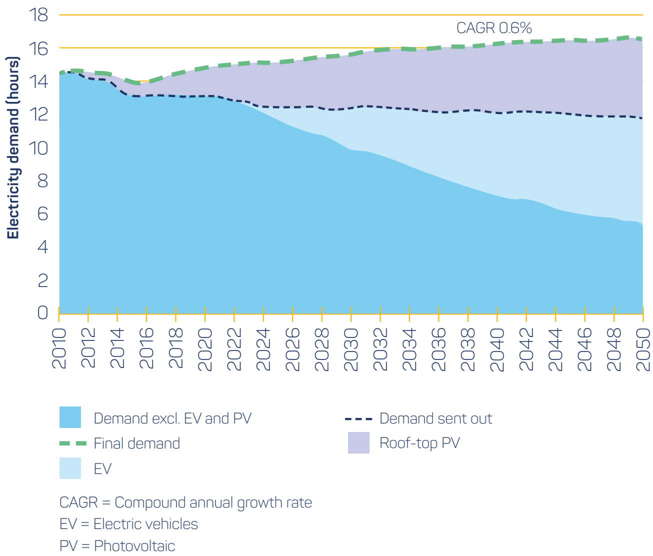


Figure G.4: Electricity demand to 2050 under the New Carbon Price (top) and Strong Carbon Price (bottom) scenarios

Source: Ernst & Young

Notwithstanding projections of a slight increase in total electricity consumption over the next decade in South Australia, the proportion of electricity that would need to be supplied from centralised generation is likely to fall. This is the outcome under either the new carbon price or the strong carbon price scenario.

The electricity demand profile in South Australia was estimated in 2030 and 2050 from data showing network demand at 30-minute intervals in each consumer category: household, business and industry for a full year.[28]

The demand that a nuclear power plant operating as a baseload facility in South Australia could meet was determined on the basis that energy from a nuclear plant would be dispatched after residential solar PV and wind generation.

EXTENT OF DEMAND FOR A NUCLEAR PLANT TO SUPPLY ELECTRICITY IN SOUTH AUSTRALIA

An average operational capacity factor for a large nuclear power plant was estimated to be 92 per cent and for a small modular reactor of 93–95 per cent.[29] That was based upon the capacity factors of modern plants operating in the USA.

Assuming the lowest cost mix of generation and a strong carbon price, the analysis showed:

- half of the annual electricity output of a large nuclear power plant
- 63 per cent of annual electricity output of a small modular reactor[30] would be dispatched within the South Australian region of the NEM.

When there was an excess of supply it was assumed that the balance would be exported to the eastern regions of the NEM through an expanded interconnector of 2000 MW capacity.

RESULTS OF ANALYSIS OF VIABILITY

The introduction of a large nuclear power plant into the South Australian region of the NEM in 2030 as a baseload plant would have an immediate impact by reducing the wholesale regional reference price of electricity in South Australia: see Figure G.5. It would be reduced by about 24 per cent, or $33/MWh, under the strong carbon price scenario.

In comparison, the introduction of a small modular reactor into the South Australian region of the NEM in 2030 would be expected to reduce wholesale prices by approximately 6 per cent, or $8/MWh.

In contrast, the integration of combined cycle gas turbine, or gas turbine with carbon capture and storage, does not have any impact on wholesale prices.

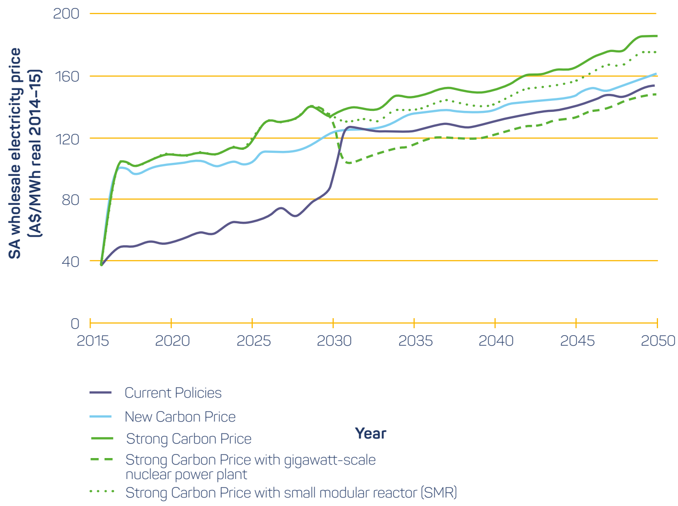


Figure G.5: Annual average real wholesale electricity price in South Australia, 2014/15 prices

Source: Ernst & Young

That is because these generators do not operate in periods of increased supply from renewables or low demand, but only operate when the wholesale price of electricity is greater than their cost of operation.[31]

Based on the annual generation output of both a large and small nuclear plant and the prevailing wholesale price, the revenues of a large and small nuclear plant were estimated. From those revenues and based on the costs discussed earlier, an analysis of profitability showed that both the small modular reactor and large nuclear power plant options consistently deliver strongly negative outcomes under either carbon price scenario on a commercial rate of return of 10 per cent: see Table G.3.[32]

An investment in a combined cycle gas turbine (CCGT) system was found to be viable under all emissions abatement scenarios irrespective of when the facility is commissioned.[33] The viability of installing CCGT with carbon capture and storage was, in comparison, assessed using a different approach that accounted for both the cost and inherent uncertainty associated with proving its feasibility. It was found that it would not be commercially viable due to the significant costs associated with proving the stability of CO_2 in underground geological formations.[34] This is discussed in more detail in Box G.1.

Table G.3: Profitability at a commercial rate of return (10%) for large and small nuclear power plants and combined cycle gas turbine plants commissioned in 2030 or 2050 under the new carbon price and strong carbon price scenarios (internal rates of return provided in parentheses for all scenarios)

Net present value (A$ billion 2015)	New carbon price		Strong carbon price	
Year commissioned for operation	2030	2050	2030	2050
Small modular reactor (285 MWe)	–2.2 (4.8%)	–1.9 (5.1%)	–1.8 (5.9%)	–1.4 (6.6%)
Large nuclear reactor (1125 MWe)	–7.4 (4.5%)	–6.4 (4.8%)	–6.3 (5.6%)	–4.7 (6.4%)
Combined cycle gas turbine (374 MWe)	0.22 (13%)	0.37 (14%)	0.32 (14%)	0.57 (16%)

Source: DGA Consulting/Carisway

Table G.3 also shows in brackets the internal rate of return that would correspond to the net present value of the investment being equal to zero. These internal rates of return show that a nuclear power plant would be profitable if it received finance at a cost of capital of between 4.5 per cent and 6.6 per cent. While commercial finance is not typically available at this interest rate, if a nuclear power plant were developed as a public project or received a guarantee on debt from a public institution, it might be profitable.

SENSITIVITY ANALYSIS

A sensitivity analysis reflecting a higher cost of meeting abatement goals and a lower consumer uptake of storage was undertaken based upon a higher carbon price (25 per cent higher than the base case) and a lower uptake of residential storage technologies (40 per cent lower than the base case).

This led to a wholesale electricity price (shown in Figure G.6) estimated to be 49 per cent higher in 2050 than under the base strong carbon price scenario.[35]

To assess the potential viability of nuclear power under this scenario, a comparison was made between the levelised cost of electricity of the large nuclear reactor and small reactor options and the levelised price of electricity they would receive over their lifetimes. It was assessed that if the levelised cost of electricity was lower than the levelised price of electricity, a nuclear power plant could be commercially viable in South Australia.

Even with the higher wholesale prices of that scenario, investment in a large nuclear plant would not be viable at present costs. However, as shown in Figure G.7, it might be viable if it were able to be delivered for a cost that is 8 per cent less than the current estimates set out in Table G.1.[36] The same result would prevail, at current costs, if finance could be obtained at 7 per cent: see Figure G.8.

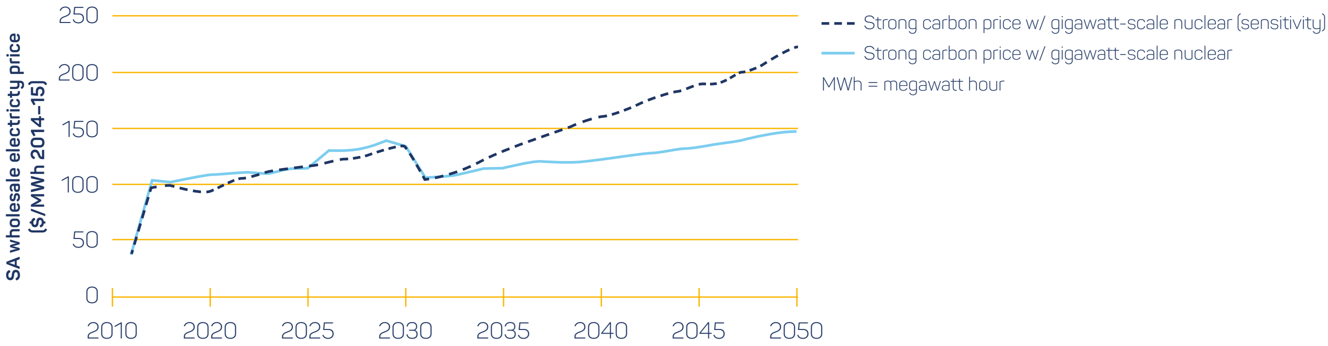


Figure G.6: Annual average real wholesale electricity price in South Australia, 2014/15 prices, Strong Carbon Price sensitivity

Source: WSP/Parsons Brinckerhoff

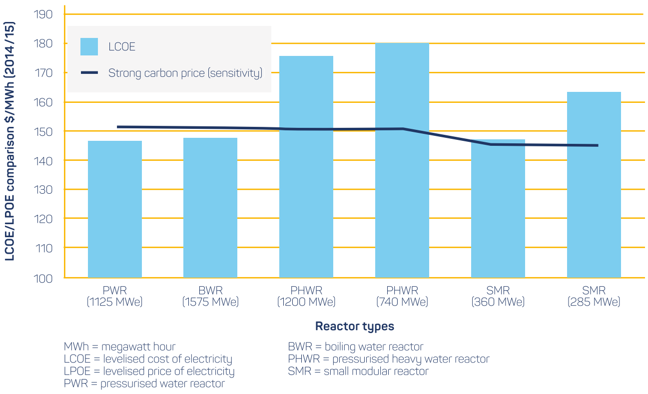


Figure G.7: Low capital cost

Source: WSP/Parsons Brinckerhoff

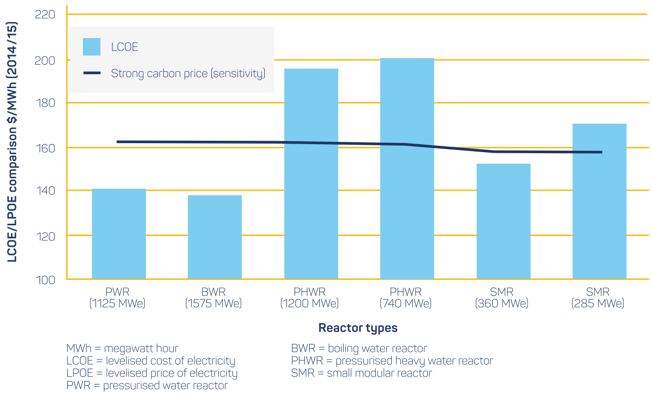


Figure G.8: Low finance cost (7 per cent)

Source: WSP/Parsons Brinckerhoff

2. ANALYSIS OF ECONOMIC IMPACTS —COMMISSIONED STUDY

Economic modelling using a general equilibrium model was undertaken by Ernst & Young to assess the potential effect on the wider South Australian economy of investments being made in either a small or large nuclear power plant. It estimated changes in key measures of economic activity such as gross state income, gross state product, wages and employment.

The modelling undertaken used the transparent, peer-reviewed model maintained by the Victoria University Centre of Policy Studies known as the Victoria University Regional Model (VURM).[41] This model has been used widely in Australia to assess the effects of investments made in one part of the economy on economic activity more broadly.

ASSUMPTIONS AND INPUTS

The potential macroeconomic impacts of investing in either a large nuclear power plant or a SMR (285 MWe) were assessed. Given that the business case assessments showed that investment in a nuclear power plant would not deliver a rate of return greater than the commercial benchmark of 10 per cent, for the purposes of the model it was necessary to assume that a substantial subsidy was made to fund its development.[42] It was assumed that this subsidy would only be provided for an investment in either a small or large nuclear power plant under the strong carbon price scenario in response to a government policy decision to meet aggressive emissions reduction targets by 2050.

RESULTS

The modelling analysis showed that investment in either the small or large nuclear power plant would have negative impacts on the South Australian economy between 2030 and 2050, even though there are some positive effects over the construction phase.

This negative economic impact arises because nuclear power does not offer a source of electricity generation that can deliver a commercial rate of return through private investment alone. This outcome is indeed consistent with the business case analyses, which showed that while a nuclear power plant investment does not yield a commercial rate of return under any circumstances, an investment in combined cycle gas turbine does, even under the strong carbon price scenario.[43]

The scale of the impact depends upon the extent to which funds used to develop the nuclear plant impact expenditure on other activities which themselves generate state income.

If an investment in either a large or small plant were funded such that it does not lead to reduced state government expenditure in other areas, it leads to a modest improvement to gross state product and a modest reduction in gross state income in 2049–2050: see Table G.4 and Table G.5.

This outcome arises because a significant decrease in wholesale electricity prices in the SA region of the NEM could lead to significant electricity exports through an expanded interconnector to the eastern region of the NEM: that is, SA could become a net exporter of electricity.

The effect of investment in a large plant if it did lead to reduced state government expenditure in other areas, was estimated to be a substantial decrease in gross state income (–3.6 per cent) and gross state product of (–3 per cent) in 2049–50: see Table G.4.

TECHNOLOGICAL UNCERTAINTY IN PROVING THE VIABILITY OF CARBON CAPTURE AND STORAGE

Carbon capture and storage technologies have been put forward to the Commission as having the potential to reduce the emissions intensity of fossil fuel electricity generation technologies such as combined cycle gas turbine systems. However, while the technologies to capture CO_2 from exhaust gas streams are commercially available, there are substantial uncertainties associated with the capacity of geological reservoirs to store CO_2 and the operational integrity of these reservoirs at high CO_2 injection rates. Substantial investments in research, development and demonstration activities will need to be made to resolve these challenges.[37]

To provide a consistent basis for comparing the viability of energy systems that incorporate carbon capture and storage against technologically mature technologies such as nuclear, the cost associated with demonstrating the feasibility of the technologies must be included. Not only does this assessment need to incorporate the cost of research, development and demonstration (RD&D) activities but also a risk that, even after these investments are made, the technologies remain unproven and the entire investment is lost. To date, most research and development activities in carbon capture and storage have been based on numerical modelling analyses. To validate these numerical modelling analyses there is a need for an investment of $1bn–$2bn in site characterisation, exploration and appraisal activities.[38]

If the costs and uncertainties associated with RD&D activities are incorporated into the model, a combined cycle gas turbine system that incorporates carbon capture and storage is unlikely to yield a commercial rate of return under any scenario. This is because private investors are unlikely to make the substantial investments in RD&D activities that would be necessary to prove the feasibility of this technology. This outcome arose even if a strong carbon price was imposed across the economy.[39]

This means that substantial public investment in RD&D activities would be necessary to support the development of technologies to prove carbon capture and storage for commercial deployment with fossil fuel fired power stations. An assessment of nuclear technologies has to be considered alongside the cost of proving the feasibility of unproven technologies such as carbon capture and storage.

This method of analysis is also applicable to other immature technologies such as energy storage and geothermal energy that will require substantial investment in RD&D to realise expected cost reductions.[40] If these cost reductions are not realised, there is a substantial risk that the cost of achieving emissions reduction outcomes would be higher than has been projected.

Table G.4: Impact of investment in a large nuclear power plant on the South Australian economy in 2030 and 2050 under the Strong Carbon Price scenario

Large nuclear power plant	2029–30	2049–50	2049–50 [a]
Gross state income	$486m (0.36%)	–$7178m (–3.6%)	–$594m (–0.30%)
Gross state product	$524m (0.37%)	–$6000m (–3.0%)	$201m (0.10%)
Wages	0.11%	0.50%	
Total employment	575	620	
Direct employment	330	258	

[a] Economic impact assuming expenditure on developing nuclear power plant does not impact other government expenditure.
Note: m = million
Source: Ernst & Young

Table G.5: Impact of investment in a small nuclear plant on the South Australian economy in 2030 and 2050 under the Strong Carbon Price scenario

Small nuclear power plant	2029–30	2049–50 [a]
Gross state income	$370m (0.27%)	–$68m (–0.03%)
Gross state product	$344m (0.24%)	$107m (0.05%)
Wages	–0.02%	0.14%
Total employment	540	473
Direct employment	167	120

[a] Economic impact assuming expenditure on developing nuclear power plant costs does not impact other government expenditure.
Note: m = million
Source: Ernst & Young

NOTES

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Transcripts and submissions can be found at the Nuclear Fuel Cycle Royal Commission's website: www.nuclearrc.sa.gov.au/transcripts and www.nuclearrc.sa.gov.au/submissions