Australia's National Science Agency

Developments in Australian energy system modelling: an energy economics perspective

Newcastle EPICS Workshop

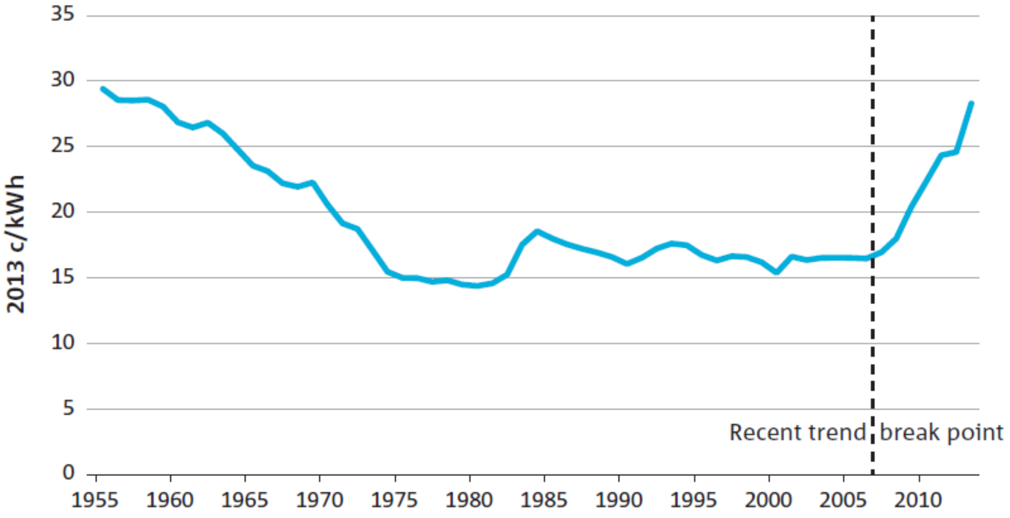
Paul Graham | January 2026

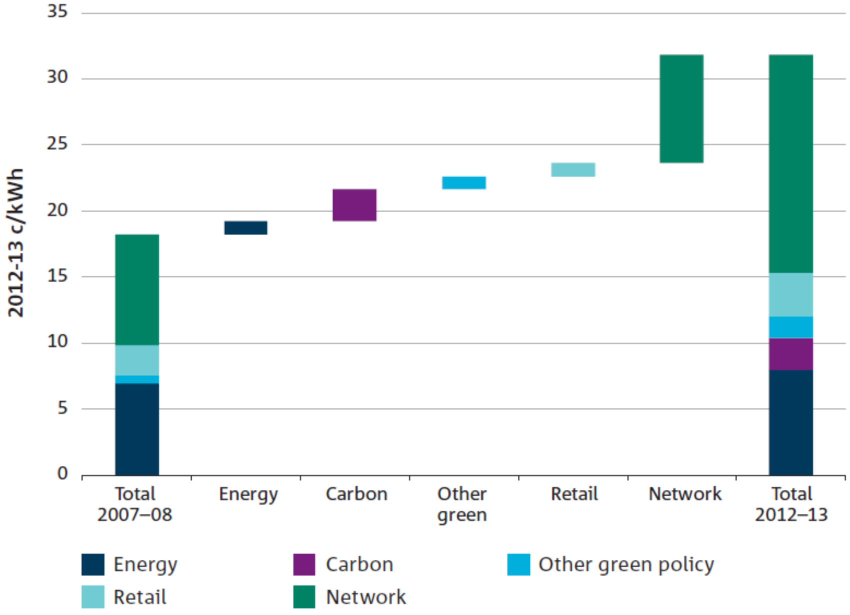
Periods of electricity cost pressures

Major pressures on electricity prices

- From 2010: Distribution companies over-invested in capacity just before demand growth stopped
- From 2010: Distribution costs under further pressure with utilisation falling due to growth of rooftop solar
- From 2015: Australia allowed international gas markets to set domestic gas price. Gas prices steadily rose and spiked substantially in 2022 due to the Ukraine war
- Post-pandemic: The cost of all generation technologies increased due to inflation and supply chain constraints following the pandemic.
- 2025-2050: Australia's net zero by 2050 target means there will be costs associated with transitioning to low emissions electricity generation

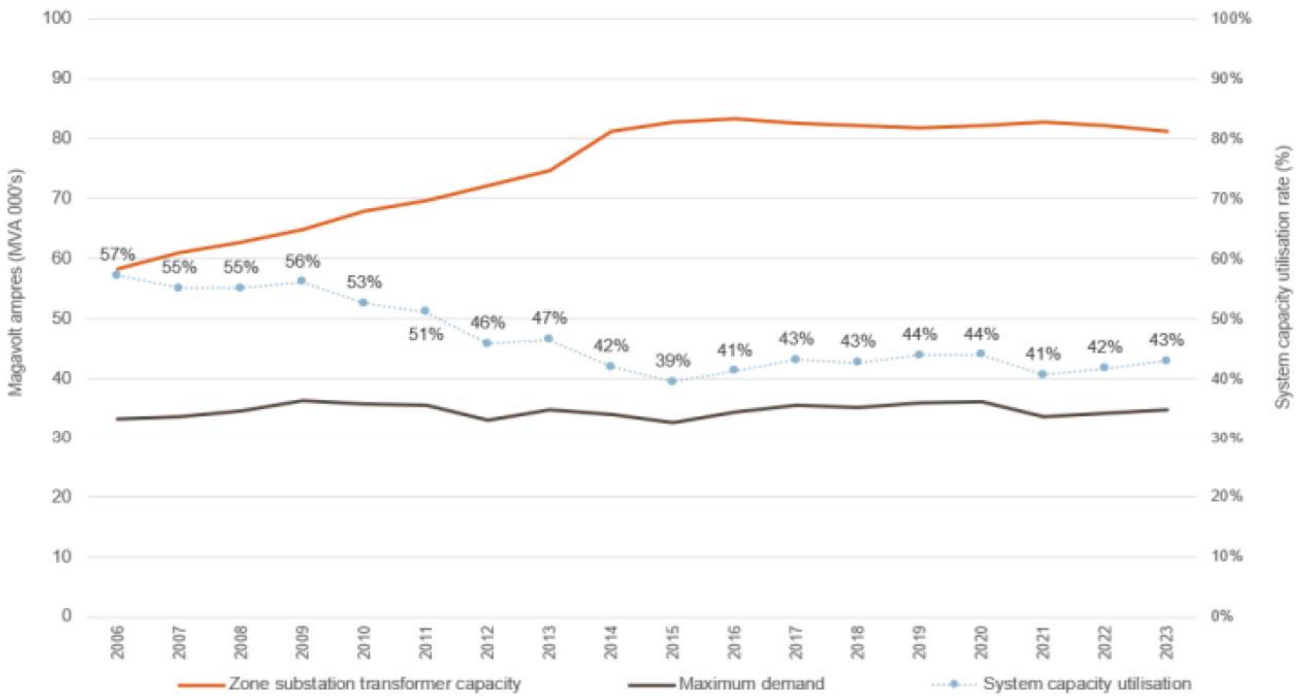
Over-investment in distribution capacity





Mitigating factor on planning error: Air conditioner ownership doubled in the first decade of 2000s

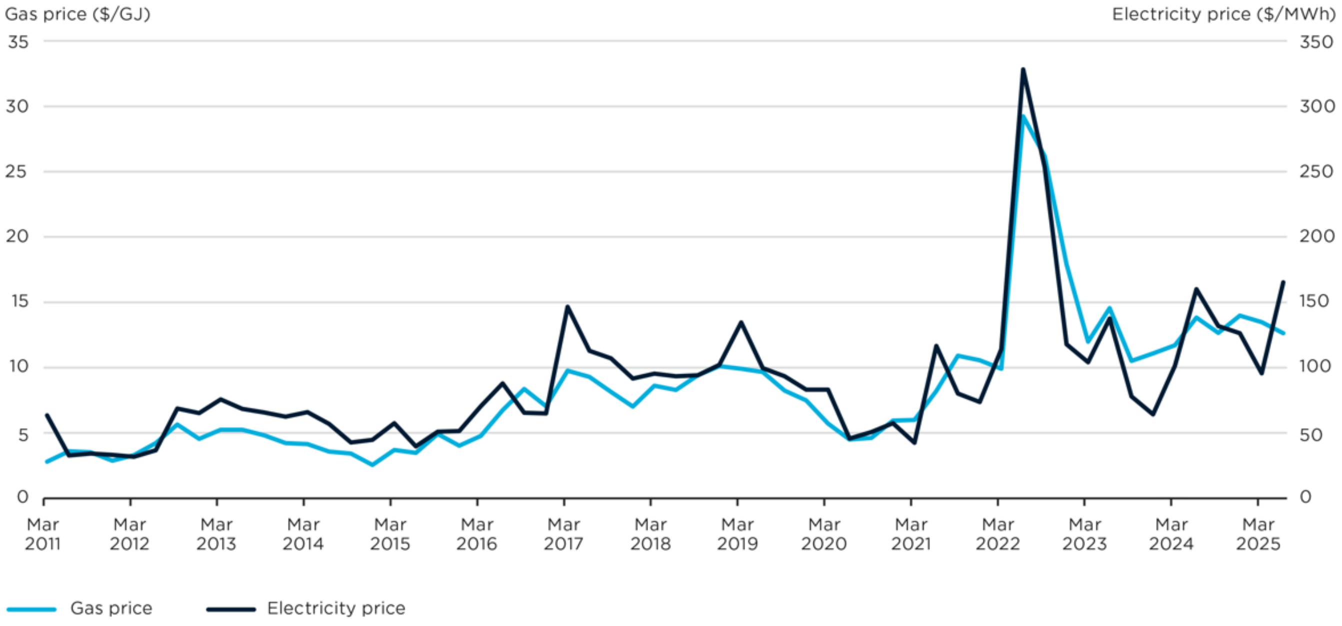
Deterioration of distribution network utilisation



- Rooftop solar uptake kicks off in 2010 and has not stopped

- Utilisation plateaus when networks stopped building more capacity (the orange line)

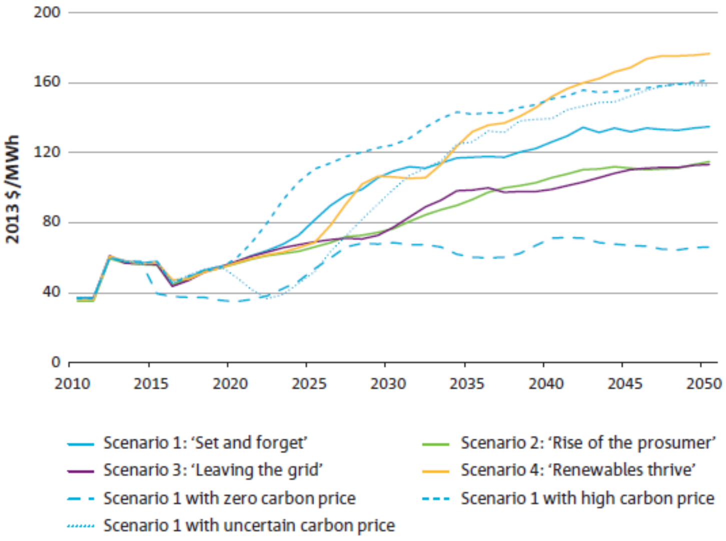
Gas prices driving electricity prices up



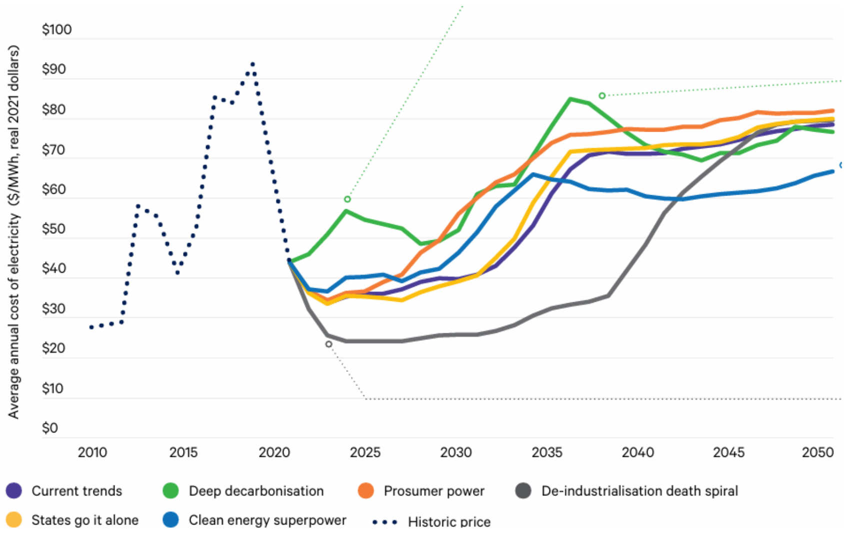
Attribution: T. Nolan, J. Gilmore and J. Munro; The role of gas price in wholesale electricity price outcomes in the Australian National Electricity Market (2021)

- LNG terminals opened in 2015
- Sanctions imposed on Russia in 2022
- Australia announced an east coast domestic gas reservation policy end of 2025

Cost of decarbonisation



Future Grid Forum



Transgrid Network Visions

Most studies tend to show an increase in costs for decarbonisation. Although, as we learn more about the best ways to support renewables the increase is flattening.

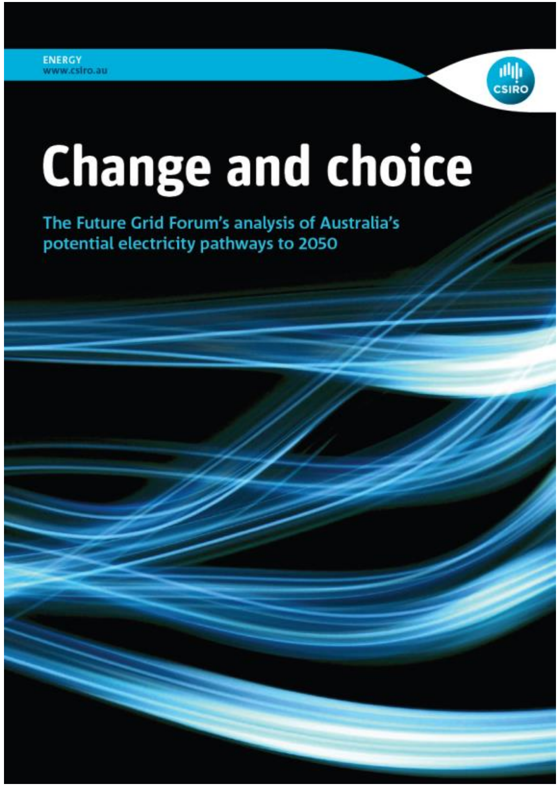
Energy Economics team responses to these cost challenges

Response to these cost challenges

- Working with industry, government and community to find consensus around the causes and possible future options and outcomes

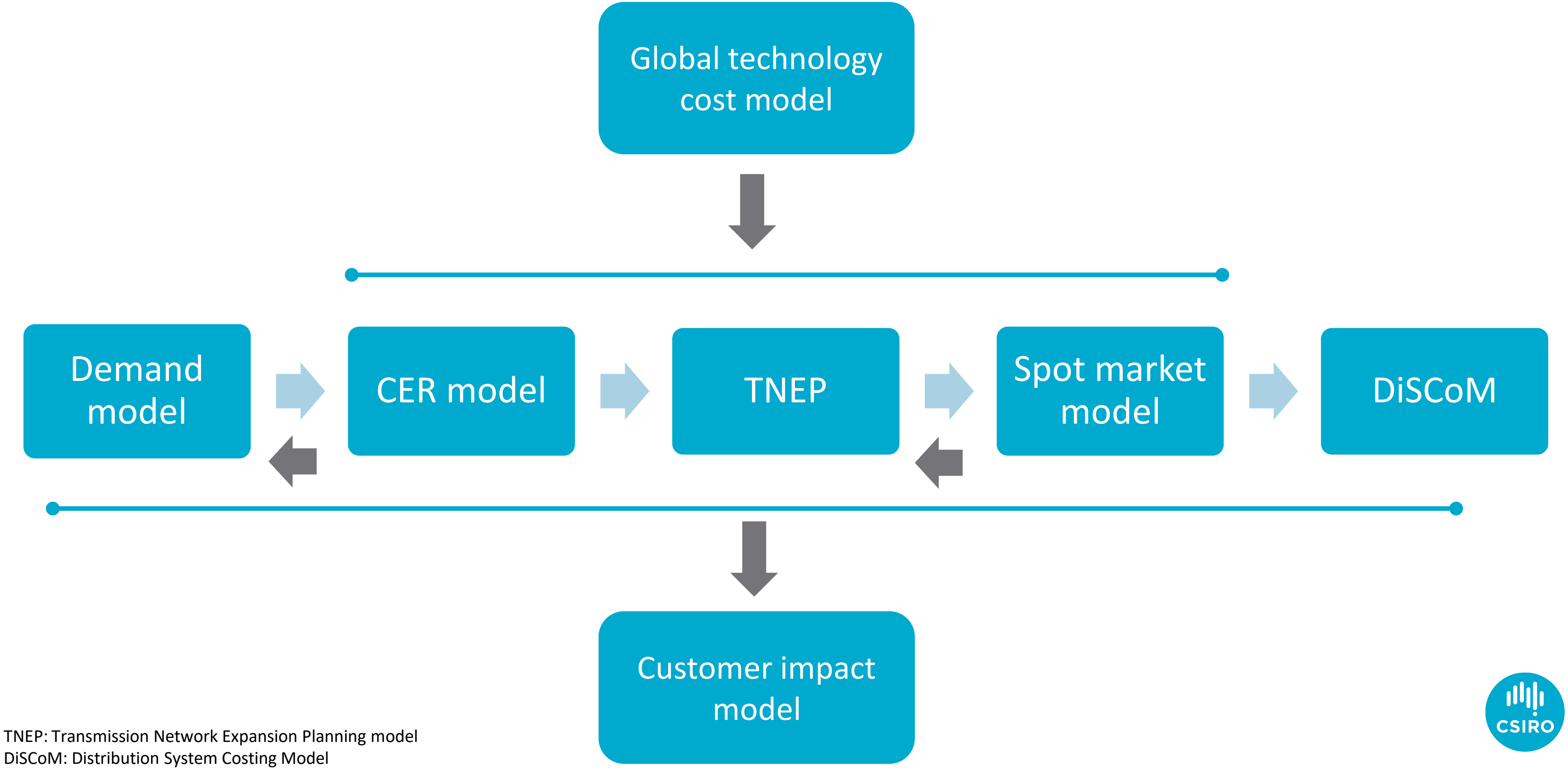
- Building modelling capability that quantifies these issues

Future Grid Forum (2013)



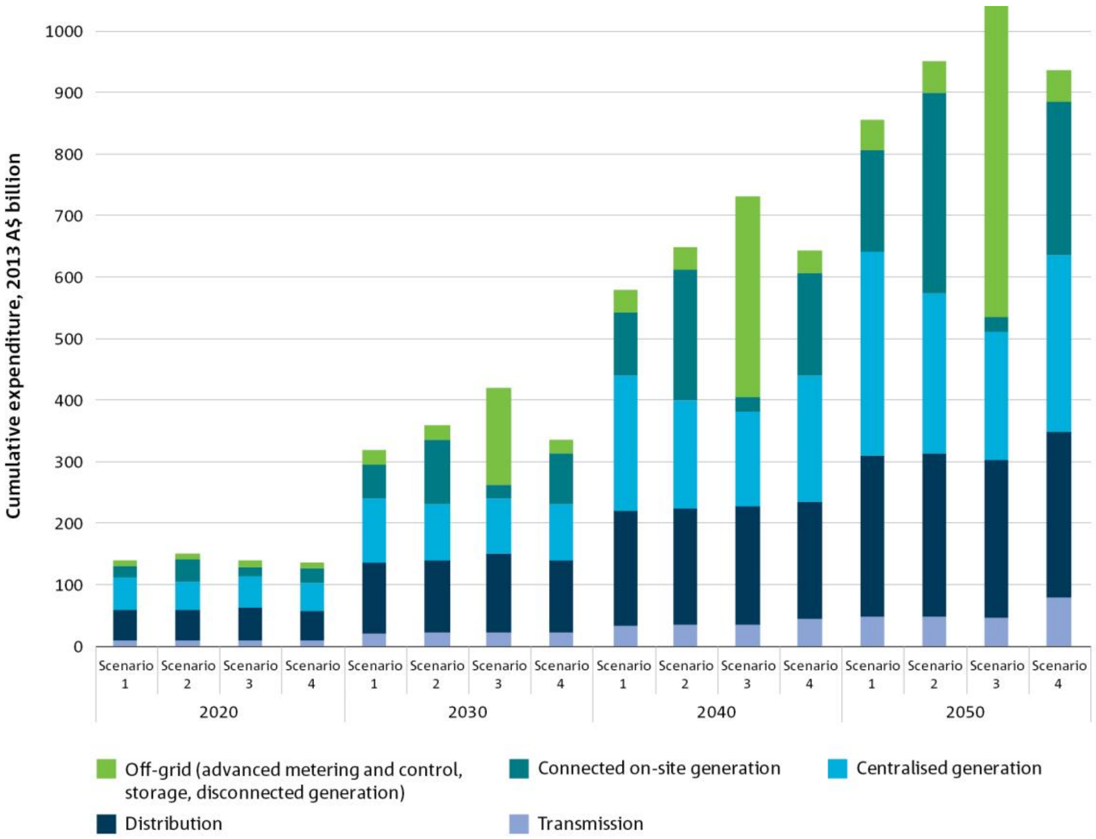
- First coalition of its type
- Focus on explorative scenarios
- First to take a whole of system modelling approach

Future Grid Forum (2013)



TNEP: Transmission Network Expansion Planning model
DiSCoM: Distribution System Costing Model

Future Grid Forum (2013)

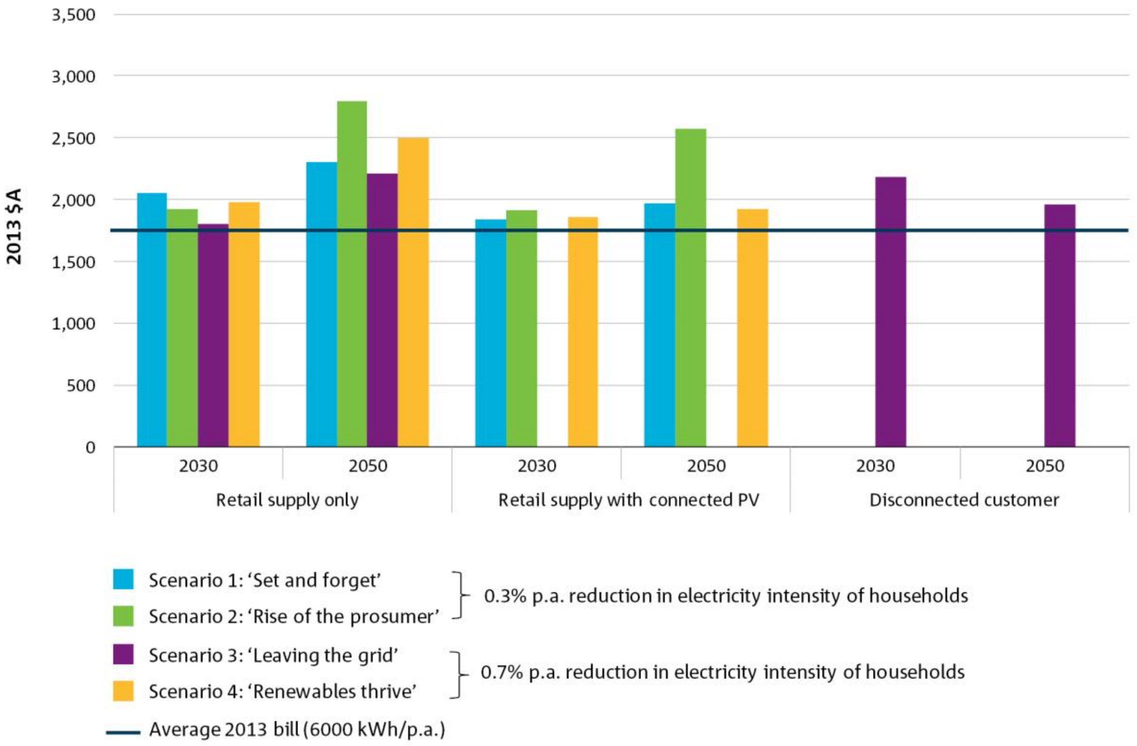


Scenarios included :

- different mixes of customer and centralised generation
- different approaches to coordinating CER
- different levels of greenhouse gas abatement

These themes all continue to be relevant

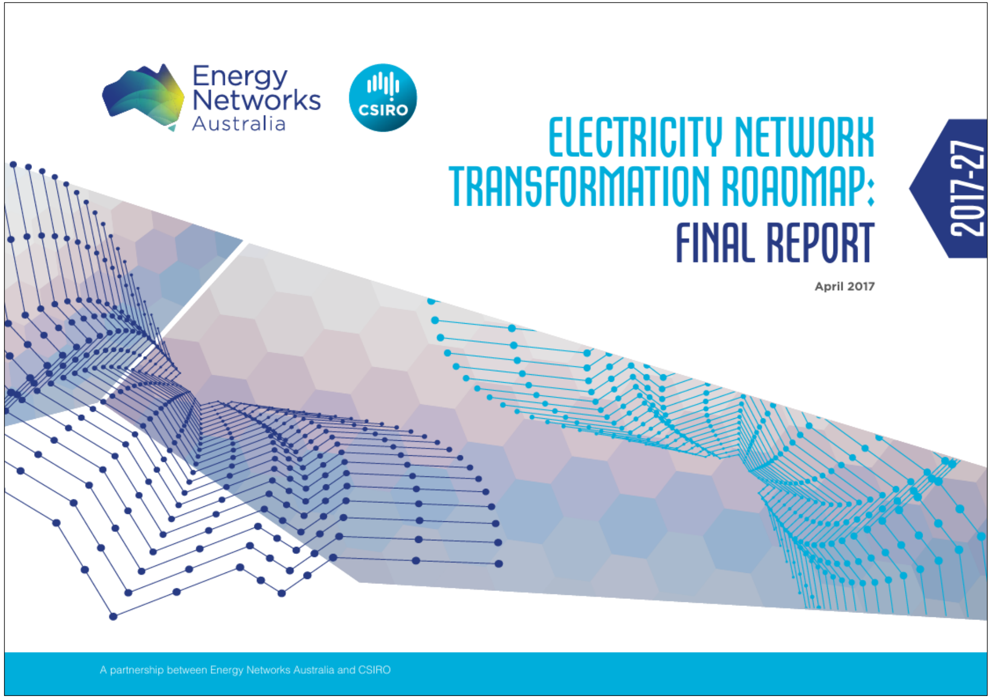
Future Grid Forum (2013)



A key advantage of modelling the whole system is that you can calculate electricity bills

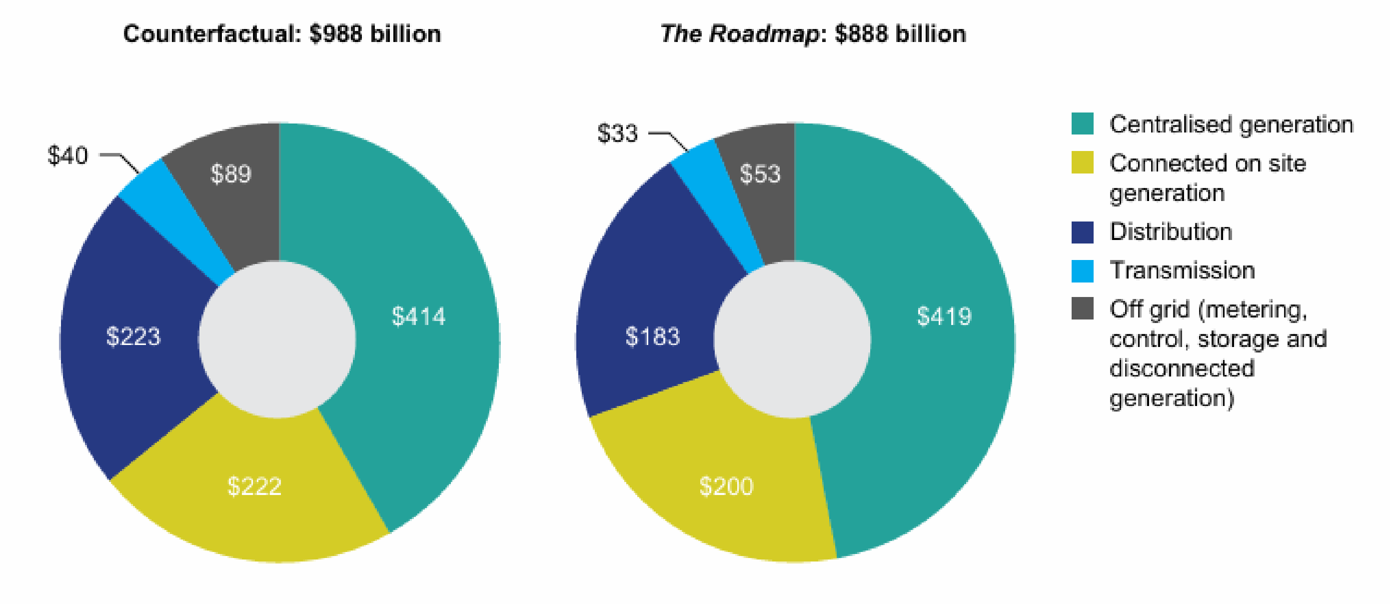
Bills are the most relevant outcome for customers and are an expression of unit system costs

Electricity Network Transformation Roadmap (2017)



An industry-led response to the finding that low utilisation would be an ongoing problem for networks unless action was taken (due to increasing uptake of CER)

Electricity Network Transformation Roadmap (2017)



A whole of system modelling approach was again used allow us to demonstrate the benefits and cost of alternative systems

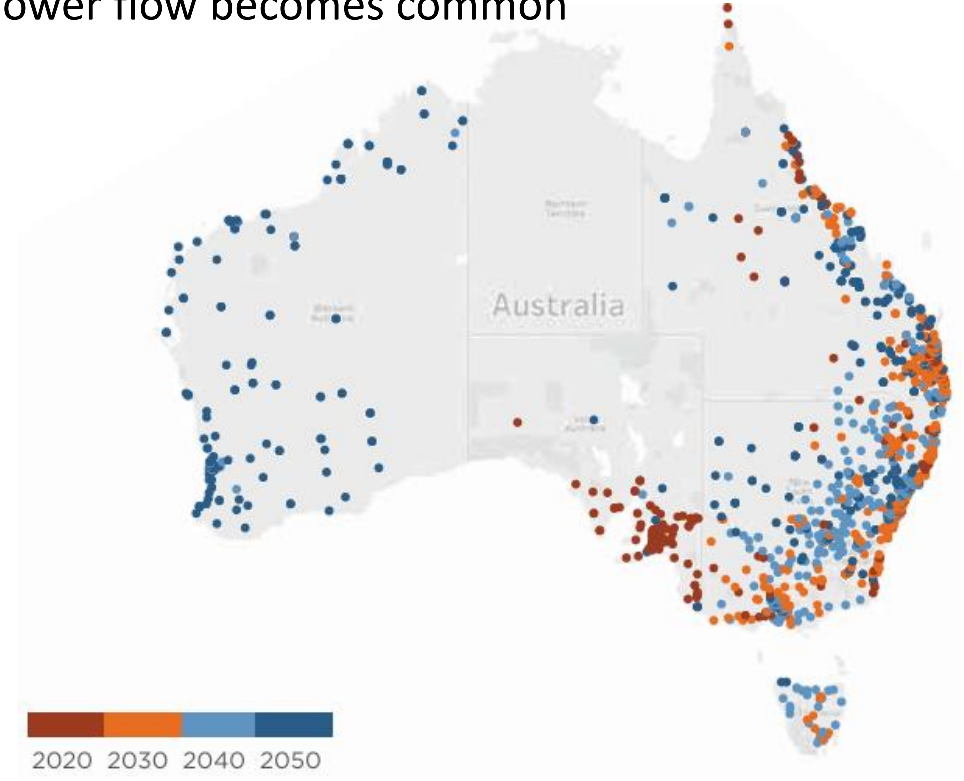
Electricity Network Transformation Roadmap (2017)

	Counterfactual			*The Roadmap*		
	Active $	Passive $	The Gap $	Active $	Passive $	The Gap $
Working Couple	$1,346	$1,811	**$465**	$1,123	$1,422	**$299**
Medium Family	$1,816	$2,601	**$785**	$1,428	$1,988	**$560**
Large Family	$2,794	$3,950	**$1,156**	$2,346	$2,734	**$288**
Single, Retired	$1,058	$1,730	**$672**	$883	$1,355	**$472**

We could also explore the equity considerations when looking at customer bills

Electricity Network Transformation Roadmap (2017)

Projected timing of when substation reverse power flow becomes common



We downscaled our demand modelling to the zone substation level.

It was a major computational feat calculating half hourly demand projections to for 2025-2050 for around 2000 zone substations

What happened after 2017?

AEMO's National Transmission Network Development Plan (NTNDP) process commenced in 2018 and evolved into the Integrated System Plan (ISP)

- Every two years
- It uses explorative scenarios
- Highly collaborative with many hundreds of stakeholders participating
- Highly transparent: lots of data and full model
- It was not whole of system but is the state of the art in integrating transmission, generation and gas modelling
- Has included factors external to electricity system – whole of economy abatement, new hydrogen opportunites

Some criticisms

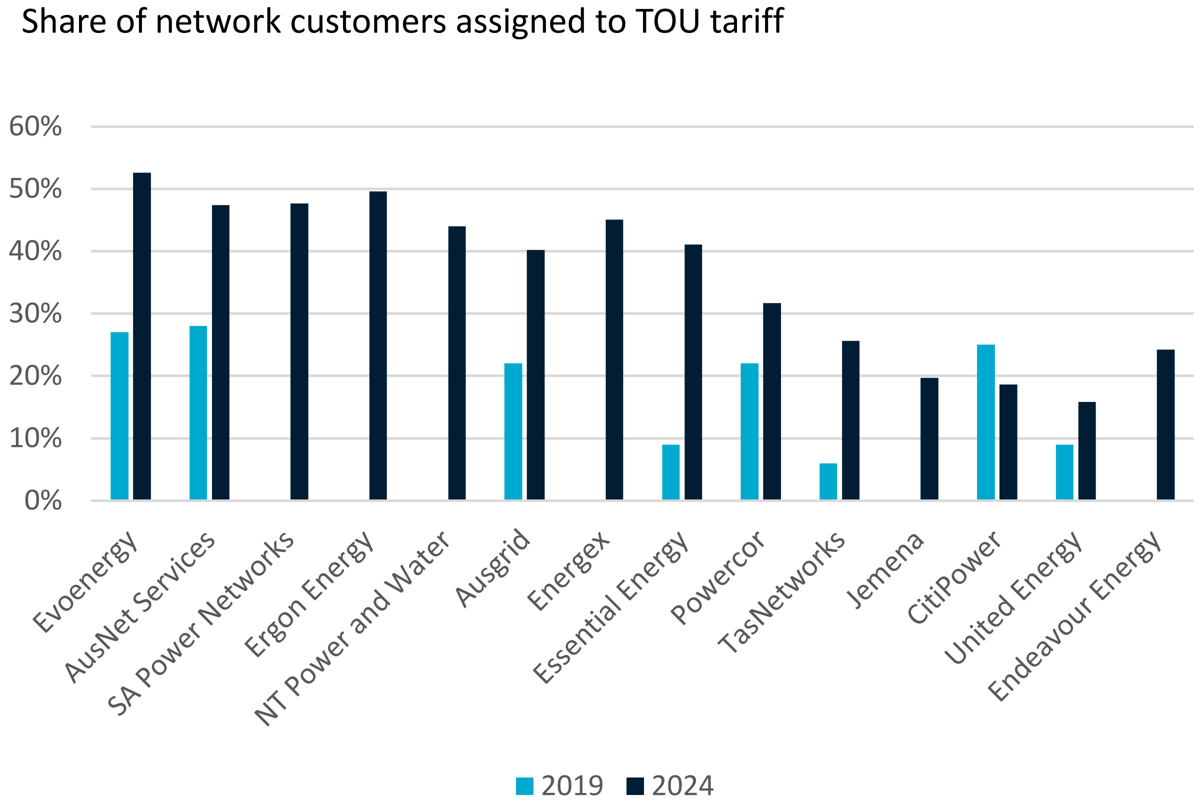
- Dominates the modelling scene. Fewer alternative public studies as a result.
- Despite transparency few organisations have the resources to repeat it

What happened after 2017?

Delivery of network roadmap

- Assignment of TOU tariffs to customers has increased substantially
- Through necessity South Australia's network has implemented
  - Solar-soaker tariffs
  - Ability to switch-off rooftop solar on a mass scale
  - Ability to run whole state on very high instantaneous levels of CER
- Utilisation not solved. Short term focus on reducing opex has helped and bought time by keeping prices moderate for a while.
- Recognition that electric vehicles are best hope for addressing utilisation – potential big volume and highly flexible.
- Some state governments have moved to ban or make customers pay full cost of any new gas distribution assets. i.e. the death spiral for gas is an accepted future

Network roadmap delivery



- Network assignment does not mean retailers must pass it through but they tend to.
- Victorian networks (last 4 on right) cannot assign customers. They must opt in. Hence, they lag other states in TOU share

Cost of decarbonisation

Technology cost projections in the first decade of the 2000s were poor

- Developed behind close doors by non-independent organisations
- During the 2007-2011 period when Australia did its deepest analysis of the cost of abatement:
  - Industry voices were ignored
  - Electricity abatement costs were substantially overestimated
  - Better projection methodologies based around learning by doing were available but not used

Global and Local Learning Model (GALLM)

CSIRO built a global model of the electricity system that included learning by doing to project technology costs

- 13 region model
- Incorporated learning from world-wide technology deployment and local in-country learning (typically on installation costs)
- Incorporated two stage learning, reducing cost reductions as technologies matured
- Three scenarios of global climate change policy

This model was a good achievement, but we still had the problems of:

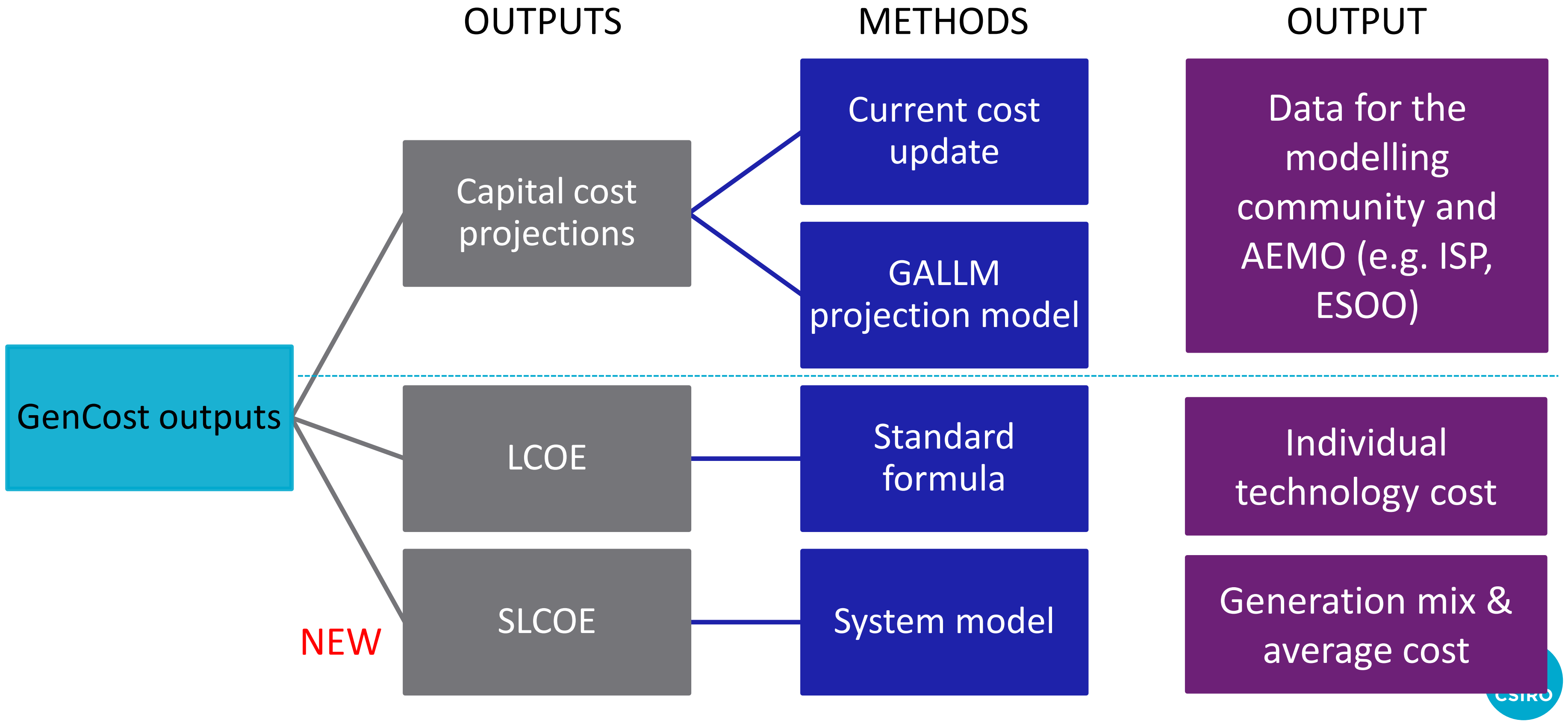
- Objectivity, transparency and consultation were inconsistent
- Projections were infrequently updated: 2012, 2015, 2017. But technology costs were moving rapidly

The GenCost project

CSIRO, AEMO and the government agreed that we would run an annual process to update technology cost projections with an emphasis on

- Broad public consultation
- Financial sustainability
  - Previous projects of this kind were too bloated and could not sustain funding
- Accessible data files for the modelling community
- Summary metrics for the policy community

GenCost project outputs



Change in method for estimating the cost of generation

STAKEHOLDER FEEDBACK

- Use a System Levelised Cost of Electricity (SLCOE) approach. SLCOE= system costs÷total useful electricity supply. Equivalent to the average electricity cost. The system boundary is generation plus new transmission (similar to the ISP).
- Provide greater transparency (open-source approach).

OBSERVATION

- Public interest in the future generation mix remains high, but the amount of published electricity system modelling has not increased. The cost and complexity of state of the art models is one of the reasons for this outcome.

New Simple Electricity Model (SEM) design

- The goal was to simplify commercial electricity model designs down to the point where it is reasonably accurate but easy to run and solves in less than an hour.
- The simplification is documented in a peer reviewed conference paper released 1/12/2025.
- WA and NT not included. This simplifies the model but also these states lack the same public data available of the NEM.
- While simpler, users still need university education, familiarity with linear programming and software licences. i.e. not designed for the general public.

2050 net zero scenarios

2050 emissions intensity target scenario		Meaning
0.20tCO_2e/MWh	NoProgessToNetZero	Consistent with achieving the 2030 82% renewables target policy target and holding the emissions intensity constant to 2050. This is not consistent with achieving net zero by 2050 but serves as a reference case cost against which reducing the emissions intensity beyond 2030 can be measured.
0.10tCO_2e/MWh	WeakNetZero	A halving of the 2030 emissions intensity by 2050. Only weakly consistent with the Australia's net zero by 2050 policy, requiring significantly more abatement in non-electricity sectors.
0.05tCO_2e/MWh	ModerateNetZero	A 75% reduction in the 2030 emissions intensity by 2050. In the range of what is required for the electricity sector to meet Australia's net zero by 2050 policy
0.02tCO_2e/MWh	StrongNetZero	The emissions intensity consistent with AEMO's 2024 Integrated System Plan Step Change scenario. Likely to be what is required to meet Australia's net zero by 2050 policy.
0tCO_2e/MWh	ZeroEmissions	Completely eliminating emissions from the electricity sector. This likely exceeds what is required to meet Australia's net zero by 2050 policy but serves to define the maximum cost of electricity associated with emissions abatement.

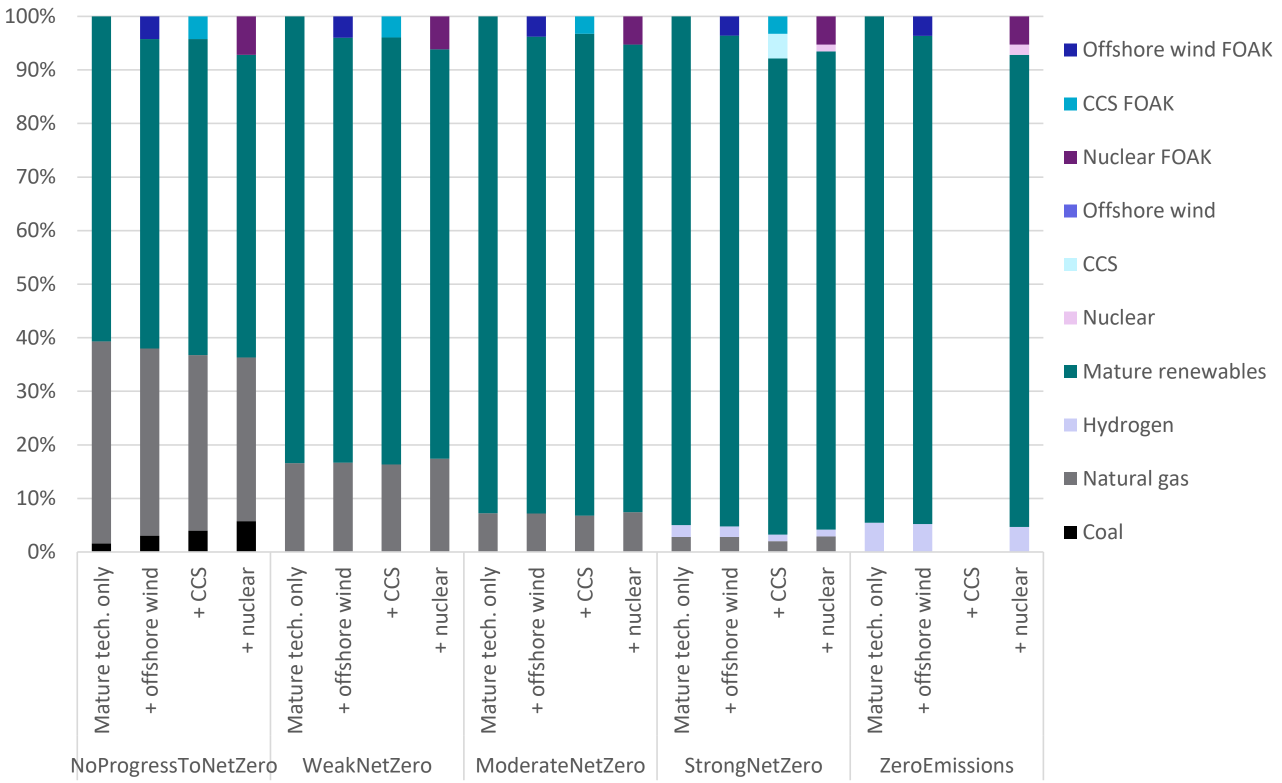
Current emission intensity is approximately 0.50tCO_2e/MWh.

First-of-a-kind premium technology scenarios

	Construction time	Premium	
Technology with limited domestic workforce experience:	Years	First project	Second project
Gas with CCS	2.0	42%	21%
Black coal with CCS	2.0	42%	21%
Nuclear SMR	4.4	92%	46%
Nuclear large-scale	5.8	120%	60%
Solar thermal	1.8	37%	18%
Wind offshore	3.0	63%	31%

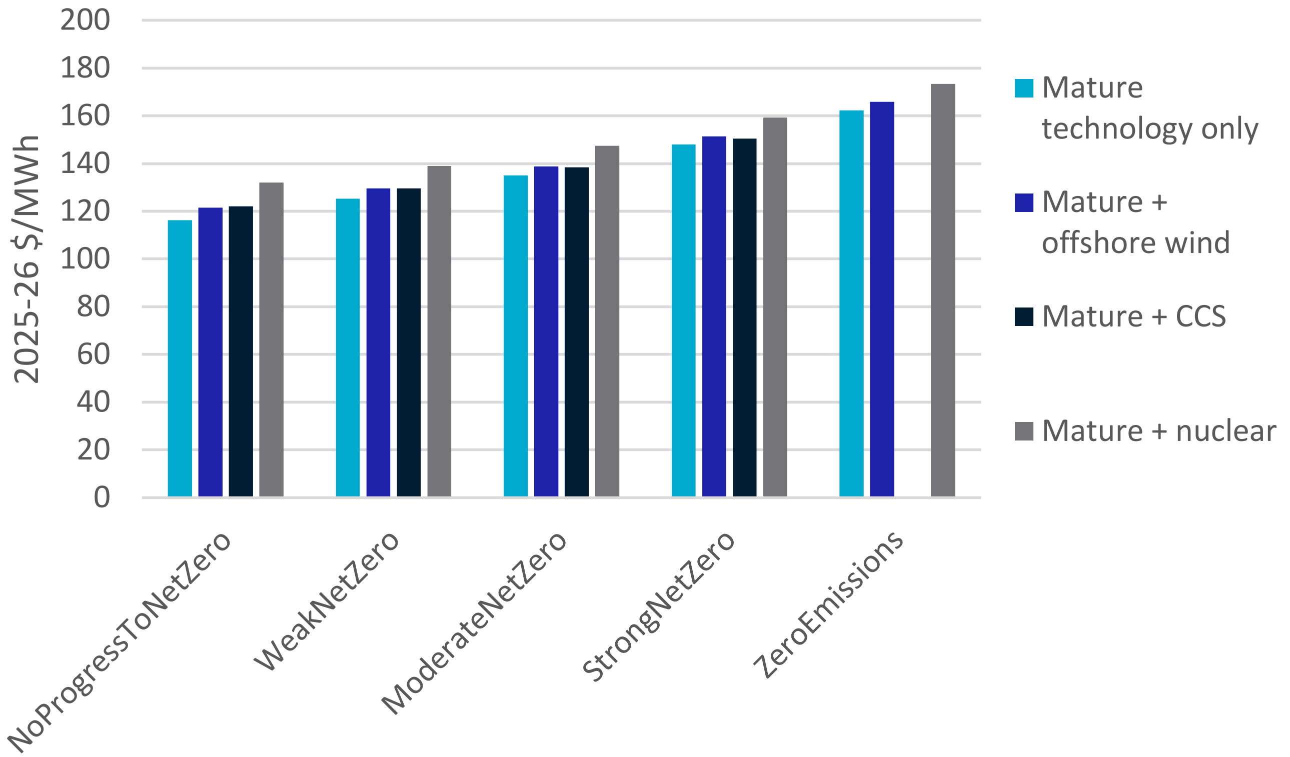
- The core scenario is “Mature technology only”. FOAK technology scenarios in 2050 are
  - +offshore wind (fixed and floating
  - +CCS (black coal and gas)
  - +Nuclear (SMR and large-scale)
- Ideally, a more complex model can determine whether to build FOAK technologies but our simple model uses scenarios. We’ve proven you get the same results either way.

2050 results: generation mix



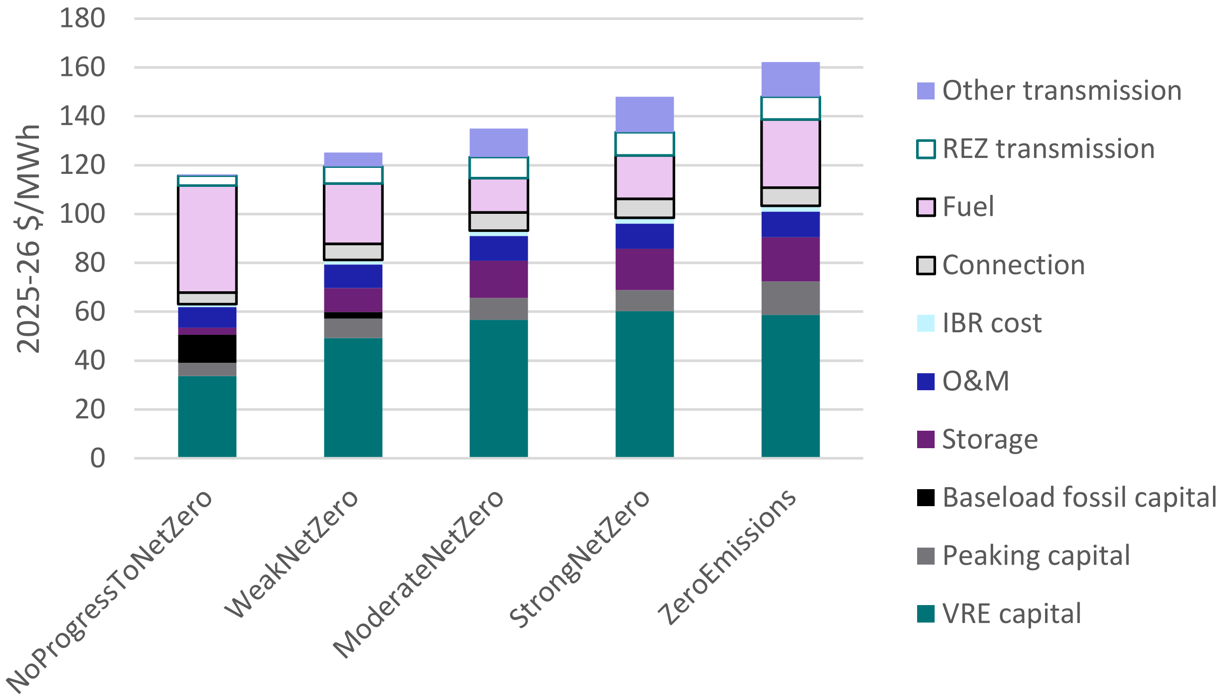
- Renewables are the dominant technology in all scenarios
- Gas share only significant at higher emission intensities
- Coal share is negligible
- In some scenarios, deployment of CCS and nuclear changes the transmission sector to make further deployment economic. But this does not mean it is competitive

2050 results: SLCOE



- Mature technology only is the least cost generation mix for all emission intensity levels.
- CCS and offshore wind scenarios have a similar cost with CCS being slightly lower cost than offshore wind. This could change in a low-cost offshore wind scenario.
- Nuclear is consistently the highest cost.

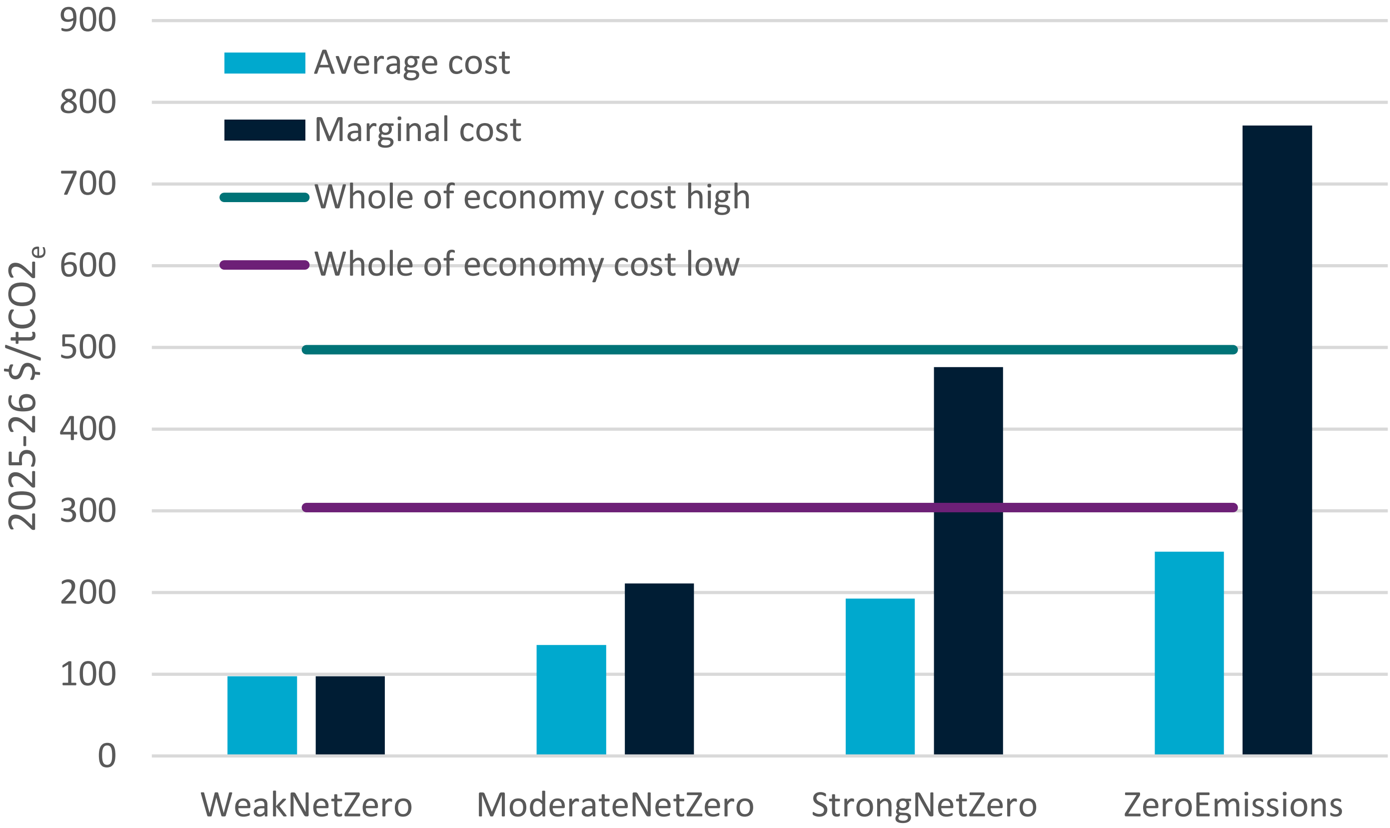
2050 results: SLCOE



VRE – variable renewable energy generation
IBR – Inverter-based resources cost such as deployment of synchronous condensers and grid-forming batteries
REZ – renewable energy zone. O&M – operating and maintenance costs

- Fuel costs fall as the gas share of generation declines but increases for the last two emissions intensity levels as hydrogen enters the generation mix.
- Baseload fossil capital costs also fall as the emission intensity declines.
- Almost all other cost categories increase as the emissions intensity falls.
- The biggest increases are in storage and transmission costs with connection costs, inverter-based resource costs and operating and maintenance cost increases relatively minor.

2050 results: electricity sector cost of abatement



Net zero conclusions

- In a whole of economy effort to reach net zero by 2050, it will not be efficient to eliminate all emissions from the electricity sector. It will be more efficient to undertake further abatement elsewhere in the economy
- The efficient range of emissions intensity of the electricity sector lies somewhere between 0.02tCO_2e/MWh to 0.05tCO_2e/MWh depending on the uncertainty in the whole of economy abatement cost.
- Achieving net zero is projected to result in electricity costs of between $135/MWh to $148/MWh in the NEM inclusive of new transmission costs or $115/MWh to $124/MWh measured as wholesale generation costs only. For context, in 2024-25, the average NEM volume weighted generation price is estimated to be slightly higher than the top end of this range at $129/MWh.
- Achieving weak or no progress in reducing electricity sector emissions in the period between 2030 and 2050 is not efficient for achieving net zero because electricity sector emissions reduction is substantially lower cost than emissions reduction elsewhere in the economy.

Why do other studies find higher costs?

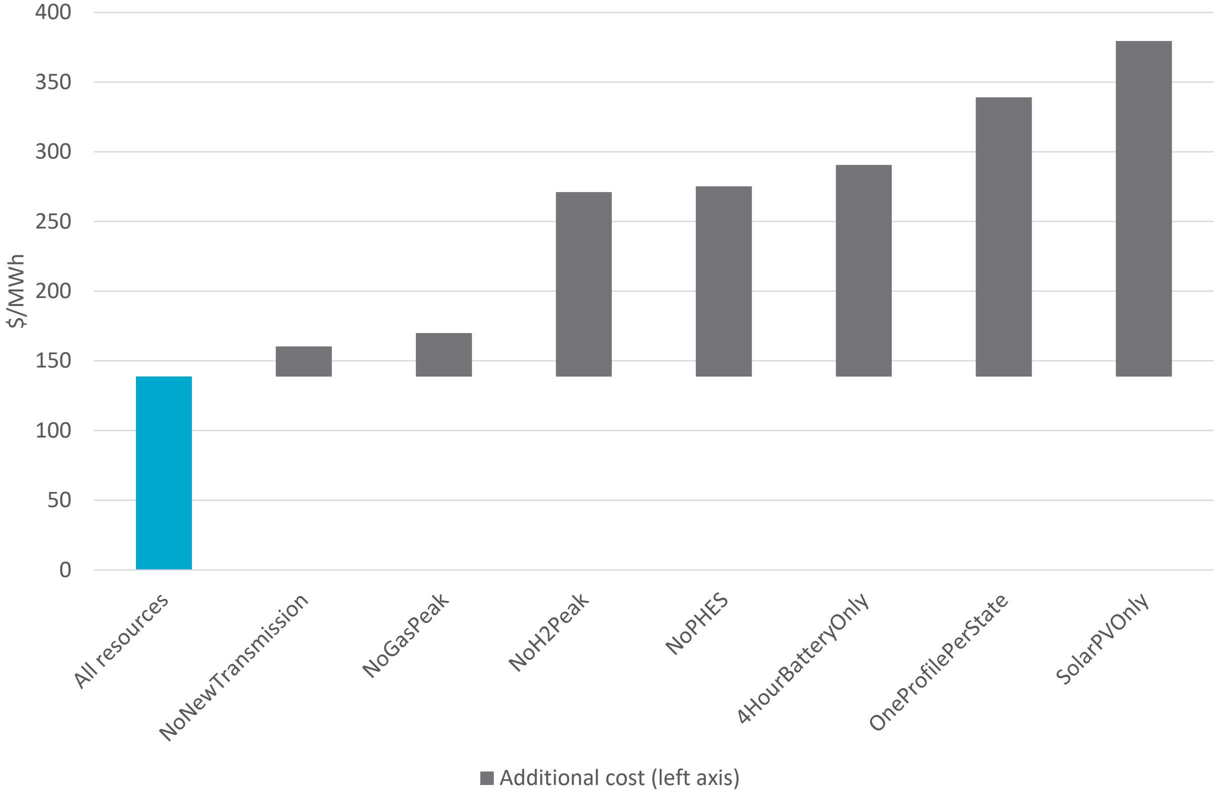
- There is a wide range of costs estimates for high renewable share systems in the literature: below \$70/MWh to over \$1000/MWh
- Our research found that in all the high cost cases the authors had excluded resources from the modelling

Graham, P. 2025, *Least-cost modelling of electricity systems with a high share of weather dependent renewable generation*, MODSIM 2025 Adelaide.

Why do other studies find higher costs?

	Idel (2022)	Cross et al (2023)	Baik et al (2021)	GenCost 2024-25
Modelled system average cost	US$225-1380/MWh at 100% share. US$97-749/MWh at 95% share	A$101/MWh at 66%, A$192/MWh at 98% share	US$71/MWh for 45% to US$150/MWh for 100% share	A$76-168/MWh at 60% share up to A$90-176/MWh at 90% share
Limiting use of fuel-based technologies such as gas turbines	Excluded in main case. A sensitivity allows for up to 5% share.	Up to 10% allowed across scenarios	Excluded. Only nuclear, CCS, hydrogen or biofuel.	10% to 40% of energy can be sourced from any fuel-based technology
Limiting storage technologies	Only batteries are included	Only batteries are included	Only batteries are included	Lithium batteries, flow batteries, compressed air and pumped hydro storage included
Limiting the duration of storage technologies	Only 3-hour batteries are allowed	Only 4-hour batteries are allowed	Multiple battery durations allowed	Multiple durations for each storage technology
Limiting diversity of renewable profiles	Single profile each for solar and wind and highest cost results include use only solar or wind separately	Single profile for solar and wind per state	Range of Californian profiles	More than 30 profiles Australia wide

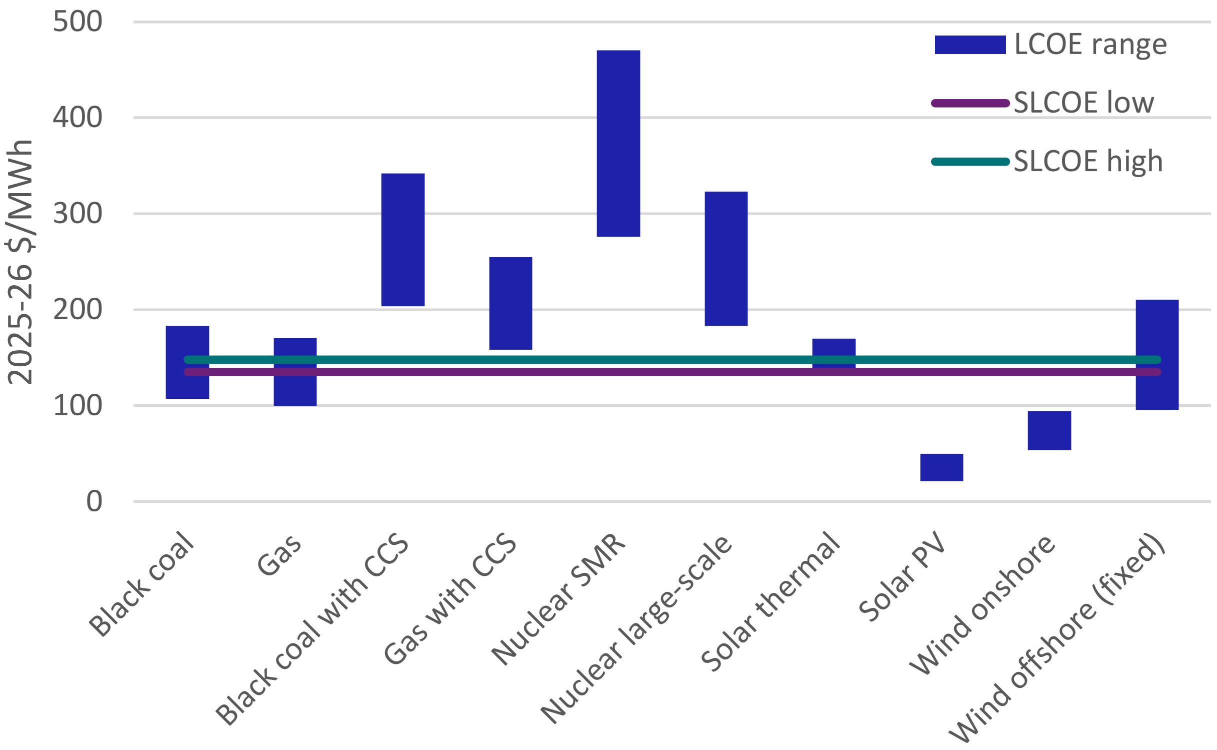
Impact of excluding resources



- Resource are cumulatively excluded in this experiment.
- Each additional exclusion increases costs.
- However: exclusions are not justified for the NEM since these resources are available.

Graham, P. 2025, *Least-cost modelling of electricity systems with a high share of weather dependent renewable generation*, MODSIM 2025 Adelaide.

LCOE: 2050 comparison to SLCOE



- While in cost range black coal not consistent with net zero.
- Gas useful except in the case where emissions must be zero.
- Solar thermal and offshore wind will have additional integration costs not shown but are in the competitive range.
- Gas with CCS is the next most competitive after renewables.
- Large-scale nuclear and black coal with CCS is next.
- Nuclear small modular reactors (SMRs) are the highest cost.

Final comments

- Economic modelling capability requirements will follow the needs of industry, government and the community
- As an economics team we've been sensitive to addressing cost drivers, but other teams are working on different problems like reliability, power quality, integration, standards and social acceptance
- These topics continue to change as we face different issues throughout the transition

Thank you

Energy
Paul Graham
Chief Economist Energy

+61 2 4960 6061
paul.graham@csiro.au