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Market pricing and revenue outcomes in an electricity market with high renewables – An Australian case study

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Outline

- Context – Renewables and pricing implications
- The Australian National Electricity Market (NEM)
- Approach and modelling methodology
- The Impact of renewables on market prices
- Revenue and profit of generators
- Key findings

Renewables and market price implications

Growing renewable penetration
- Low short run marginal cost (SRMC)
- Generators bid into the market close to SRMC (assume perfect competition)

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Reduction in spot electricity prices
- For energy only wholesale markets
- Market price would be low in most periods

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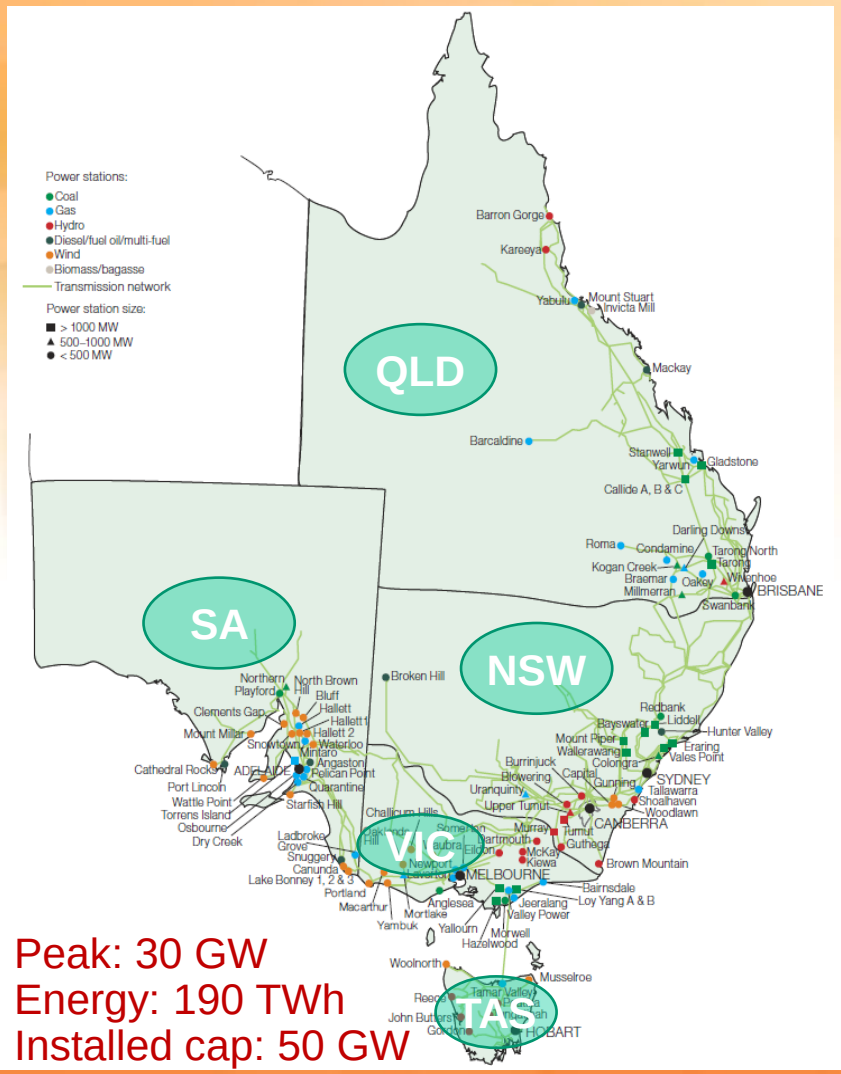
Reduce generator revenues
- Will generators earn sufficient revenue to recover cost (both short run and long run cost)?
- Questions over long-term resource adequacy

- Exploring these issues within the Australian National Electricity Market (NEM) with high wind and PV penetrations
  - Quantitative analysis of spot market prices and generator revenue
  - With a view of assessing the viability of the present energy-only market
  - Mechanisms to ensure resource adequacy and reliability

The Australian National Electricity Market



Peak: 30 GW
Energy: 190 TWh
Installed cap: 50 GW

- Covers all Eastern States – 90% of electricity demand.
- Largely coal, around 15% renewables
- Good wind and solar resources
- Energy only market
  - Gross pool – real-time market
  - 5-minute dispatch with 30-minute trading intervals
  - Reliability criteria: 0.002% USE
  - Market Price Cap: $13,500/MWh (€9,600)
  - Price floor: -$1,000/MWh

Approach and methodology

Generators obtain revenue through a spot market based on the spot price in each period

- Hourly SRMC bidding, merit order dispatch
- Spot price is set by the marginal generator

Applying a minimum synchronous constraint in each period

- The minimum amount to which aggregate conventional generators can be turned down in any of the dispatch periods

'Constrained on' Payments for out of merit order dispatch

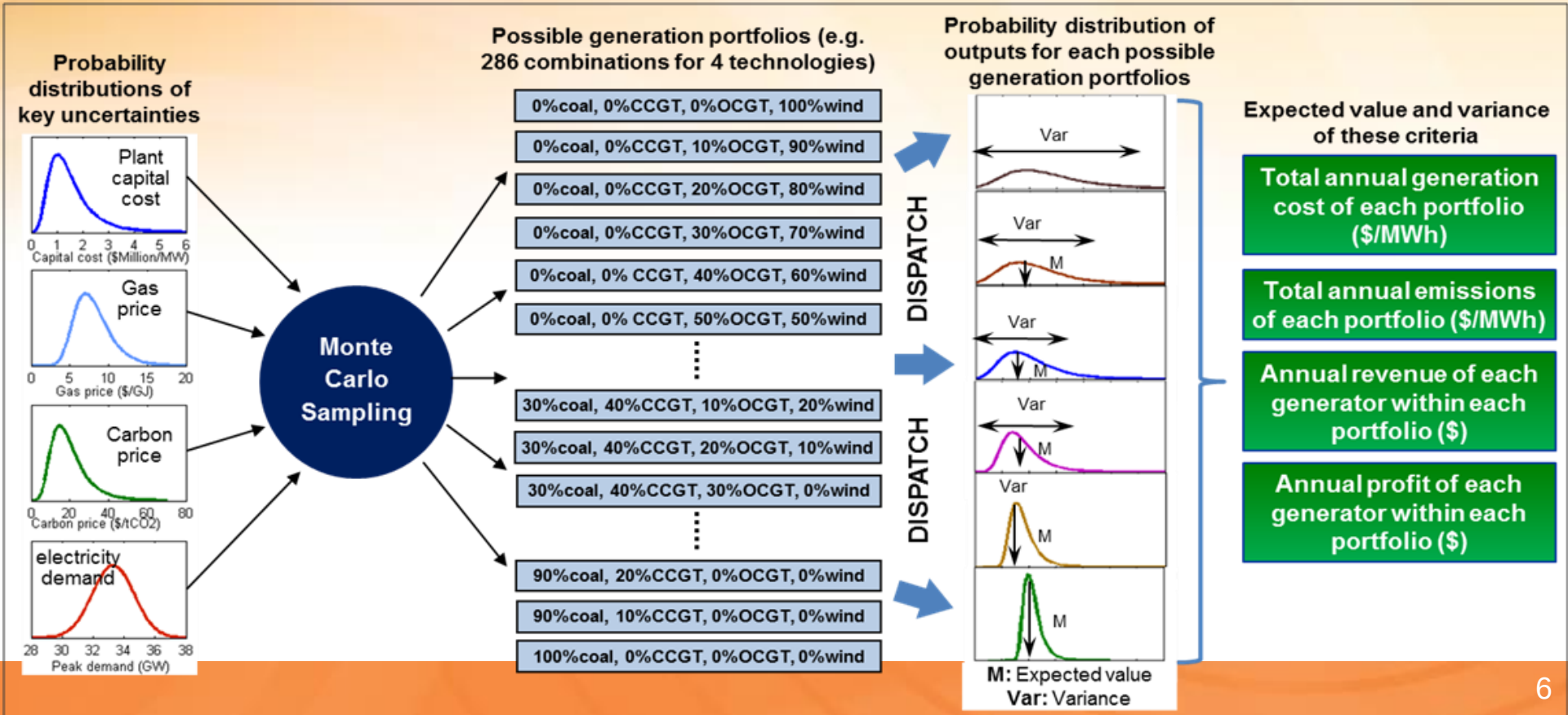
- SRMC of the most expensive generator that is dispatched to meet the synchronous constraint

$$\textit{Spot market revenue} = \sum_{t=1}^{T} P_{n,t} \times \textit{spot price}_t$$

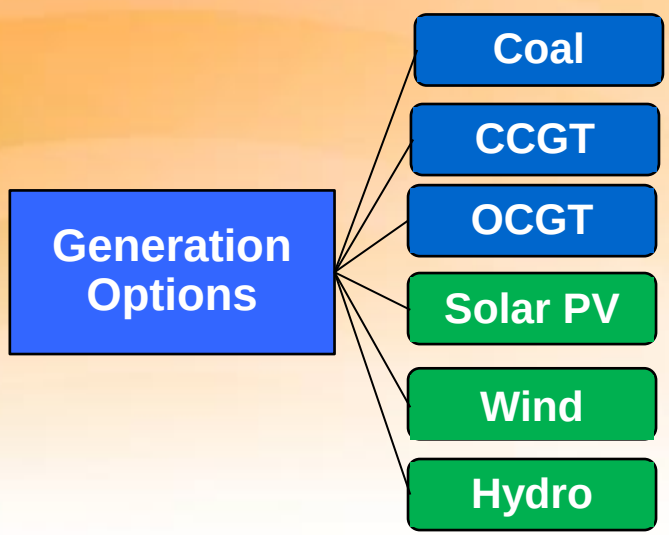
$$\textit{Annual revenue} = \textit{Spot market revenue} + \textit{Constrained on Payments}$$

Probabilistic generation portfolio modelling

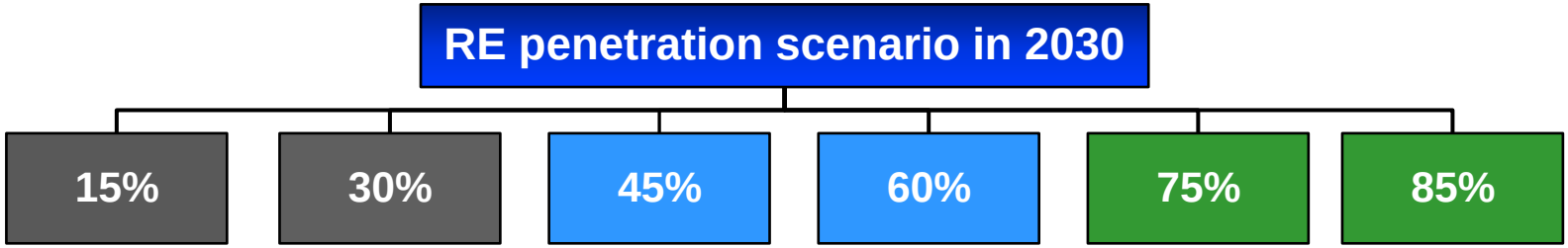
- Taking into account a range of future uncertainties (e.g. fossil fuel prices, carbon price, demand) using Monte Carlo simulation
  - "Expected" annual revenue, cost and profit are the average value across Monte Carlo runs



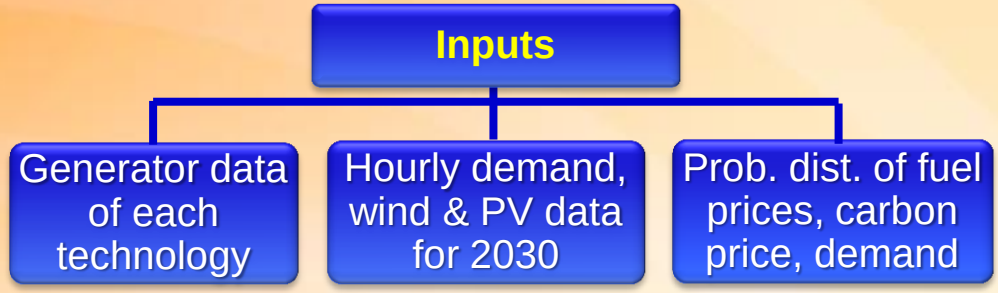
Modelling different RE penetration in 2030



- Examining a wide range of generation portfolios with different PV and wind penetration for 2030 in the context uncertain *fuel prices*, *carbon pricing* and *electricity demand*.
  - Existing capacity is taken into account
  - Different mixes of fossil-fuel technologies (coal, CCGT and OCGT)
  - Wind and PV are dispatched when available



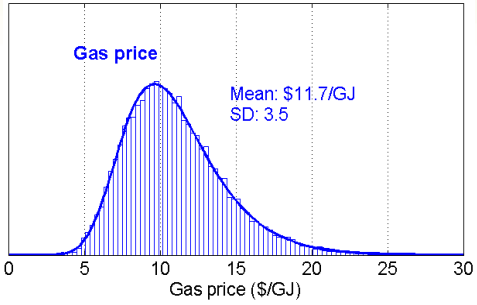
Modeling Inputs

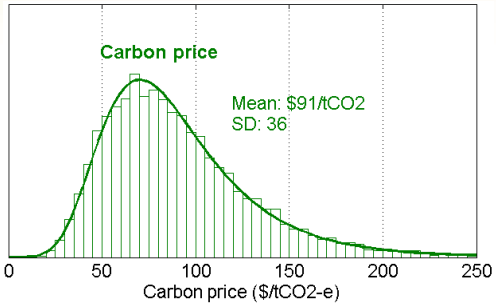


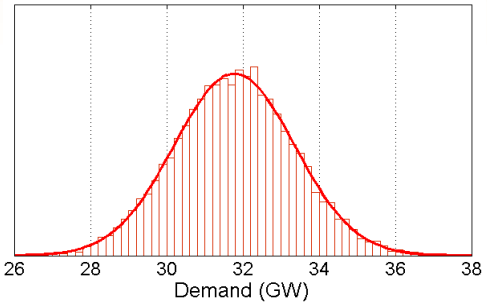
NTNDP (AEMO)
AETA (BREE)

AEMO 100% RE study

Estimated from
- AETA (BREE)
- Australian Treasury modelling



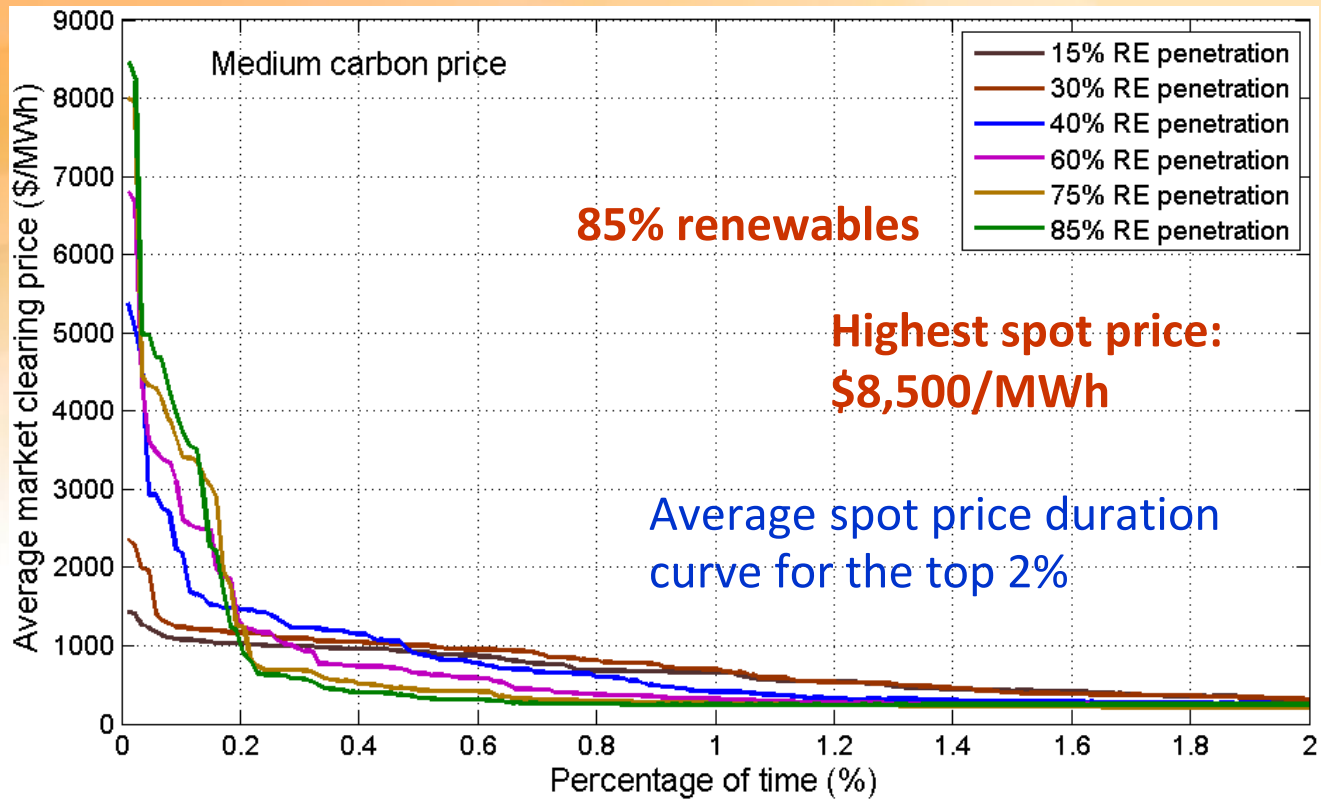




Histogram of gas price, carbon price and peak demand over 10,000 simulations

- Revenue & profit of each generation technology in each generation portfolio are calculated for 10,000 simulated fuel prices, carbon price, and electricity demand.

Impact of renewables on market prices

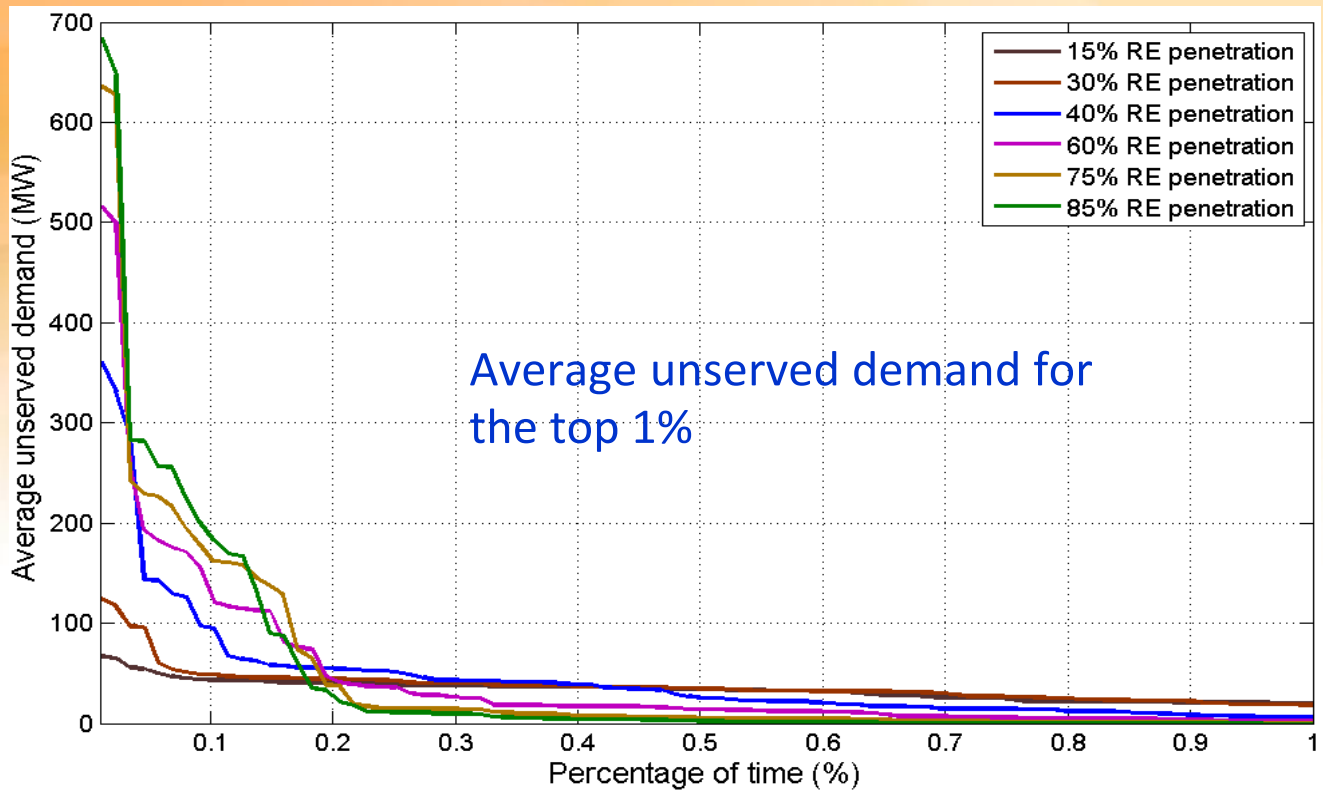


RE Penetration	15%	30%	40%	60%	75%	85%
Highest price ($/MWh)	1,400	2,400	5,400	6,800	8,000	8,500
Average price ($/MWh)	135	139	129	114	86	66
No. of high price periods (>$500)	112	114	77	56	36	28

As RE penetration increases

- spot revenues are earned in increasingly high price periods
- fewer periods of supply demand imbalance but the magnitude of unserved energy is greater (hence higher price spikes)

Unserved demand duration curve



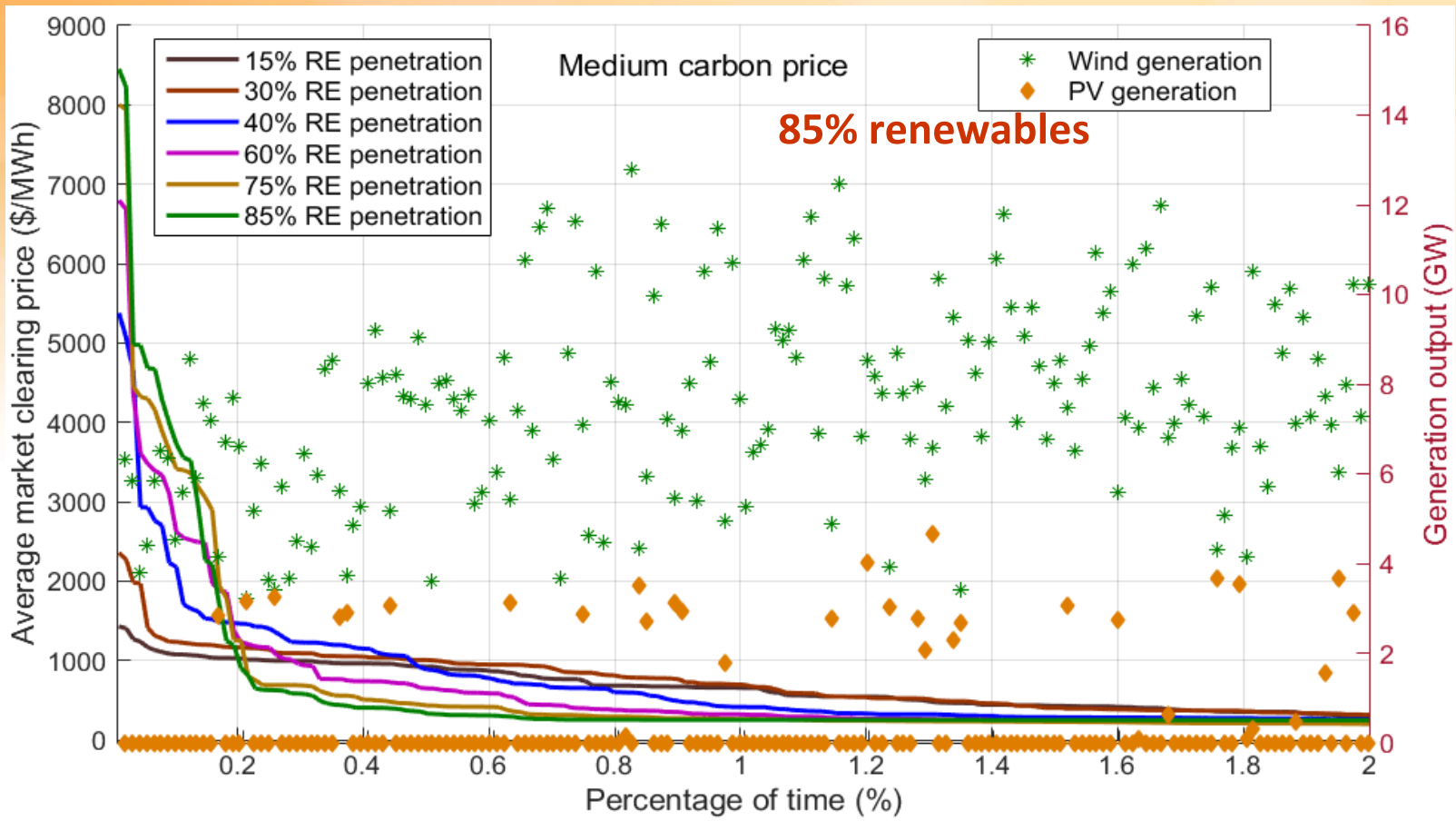
Average unserved demand duration curve for the least cost generation portfolio

	15%	30%	40%	60%	75%	85%
Highest unserved demand (MW)	70	124	360	520	630	680
Periods of unserved energy	440	390	280	180	142	83

- Unserved energy is concentrated into fewer periods as the RE penetration increases.

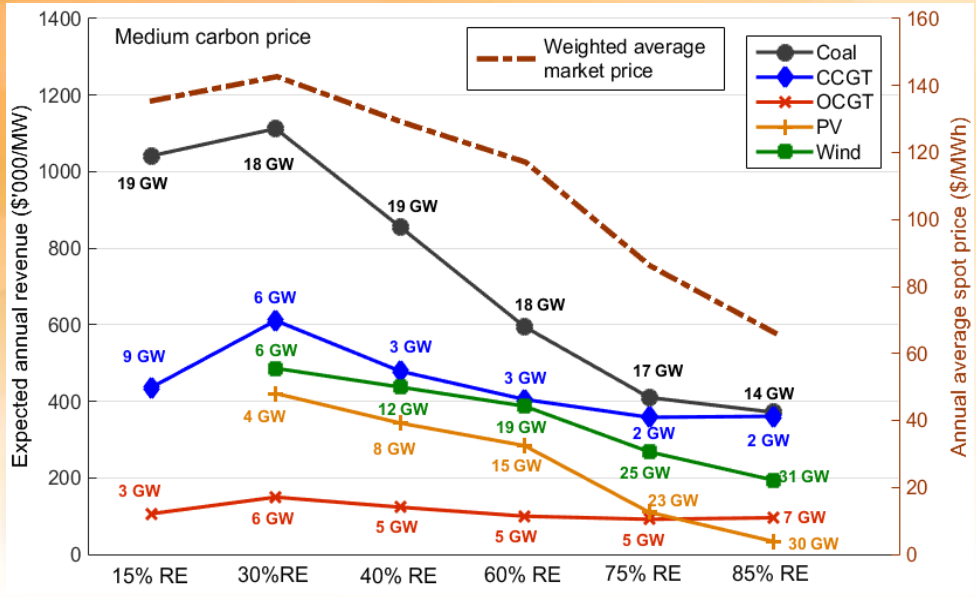
Correlation between prices and RE generation

Price duration curve with corresponding wind and PV output.

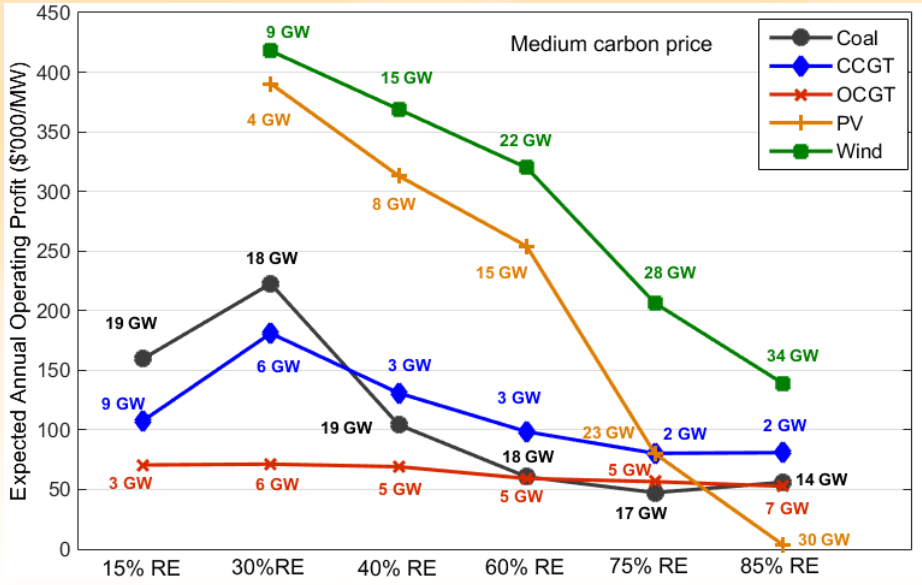


- Wind and PV do not often generate during high price periods

Annual revenue ($/MW)



Annual operating profit ($/MW)



- As renewables increase, revenue and profit of generators decrease
  - due to lower average spot prices influenced by the low SRMCs of wind and PV
- Profits of PV and wind significantly reduce with higher renewables.
  - Not often generating when prices are high
  - Greatest impact on PV (almost negligible profit at high penetration)
  - Yet to account for annual capital cost repayment.

Key findings and work underway

Avg. market prices reduce with higher renewables	• Due to low operating costs of wind and PV • Less periods of imbalance but the magnitude of imbalance is greater • Magnitude of price spikes is higher
Reduced revenue and profit	• The impact on utility-scale PV are very severe at high renewable penetrations
Changes in market mechanisms may be required	• To ensure revenue sufficiency • Capacity mechanisms? • Increase (or remove) market price cap?

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Questions?

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Approach and methodology

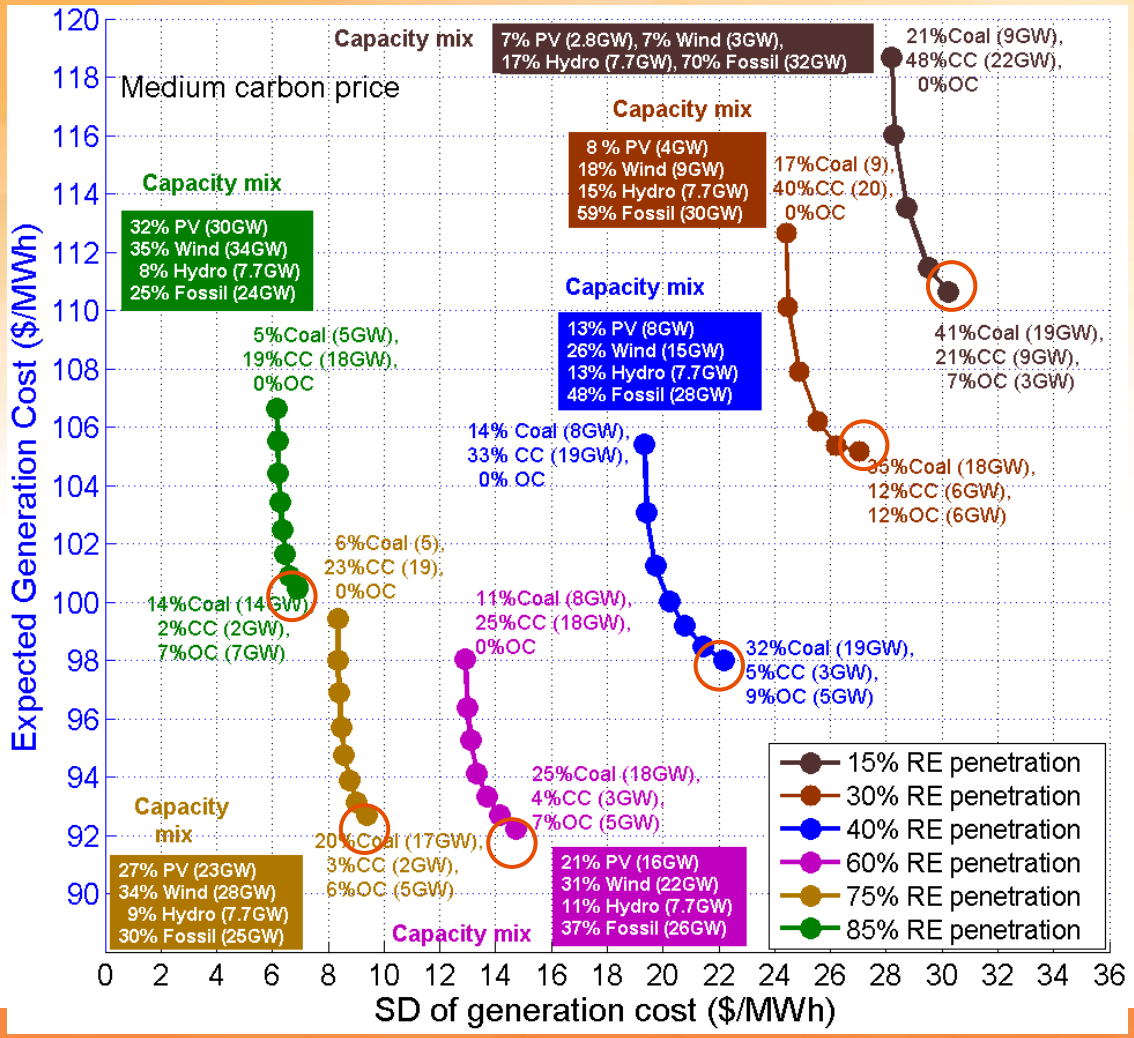
- Generators obtain revenue through a spot market based on the spot price (market clearing price) in each period
  - Hourly SRMC bidding, merit order dispatch
  - Hourly spot price is the cost to supply the last MW to meet demand (i.e. SRMC of the most expensive generator that is dispatched)
- Applying a 15% minimum synchronous constraint (SC) in each period
  - The minimum amount to which aggregate conventional generators can be turned down in any of the dispatch periods
- 'Constrained on payments' for out of merit order dispatch
  - SRMC of the most expensive generator that is dispatched out of merit

$$Spot\ market\ revenue = \sum_{t=1}^{T} P_{n,t} \times spot\ price_t$$

$$Annual\ revenue = Spot\ market\ revenue + Constrained\ on\ payments$$

Optimal generation portfolios

'Cost VS Cost risk Efficient Frontier' (EF) for each RE penetration

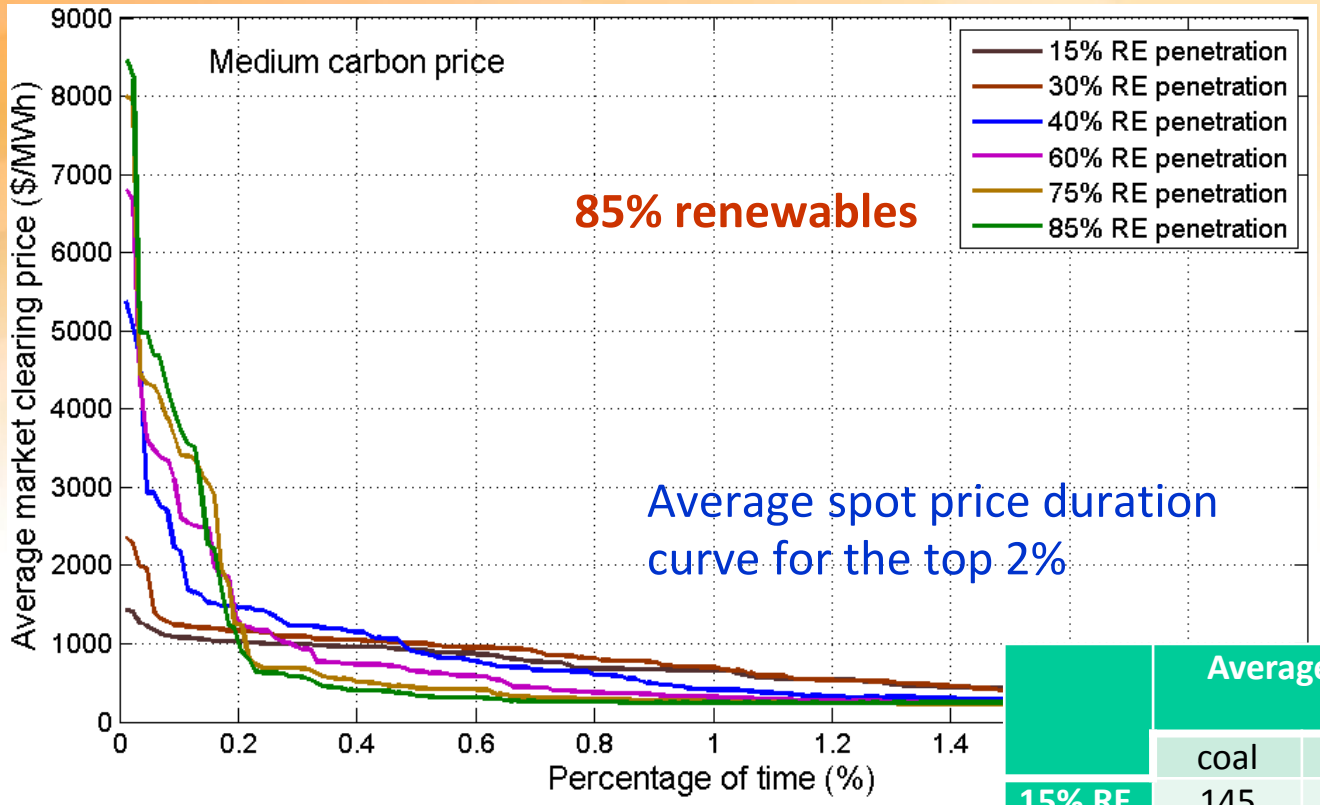


- *Expected cost (mean)* and *cost risk (SD of cost)* of generation portfolios on the 'Efficient Frontier' (optimal generation portfolios)

% RE	Cost range ($/MWh)
15%	$110 - $119 (€78 - €84)
30%	$105 - $113 (€74 - €80)
40%	$98 - $106 (€69 - €75)
60%	$92 - $98 (€65 - €69)
75%	$92 - $100 (€65 - €71)
85%	$100 - $107 (€71 - €76)

Will focus on the least cost portfolios for revenue analysis

Impact of renewables on market prices



- As renewable penetrations increase, spot revenues are earned in increasingly rare periods

Highest price: $8,500/MWh

	Average annual generation (TWh) (across 10,000 simulations)				
	coal	CCGT	OCGT	PV	Wind
15% RE	145	40.4	0.22	8.9	9.6
30% RE	134	24.9	1.4	11.1	31.8
40% RE	120	6.7	0.8	22.2	53.9
60% RE	78	5.6	0.5	44.3	74.6
75% RE	48	4.7	0.3	66.4	81.5
85% RE	33	4.5	0.7	84.8	77.3