



## Power generation portfolio analysis with high penetrations of large-scale solar PV: Implications for energy and climate policies

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### Outline

- Challenges in the electricity industry
  - Implications for generation investment decision-making
- Role of PV generation in the electricity industry
- Key policy questions regarding PV
- Probabilistic generation portfolio modelling tool
- A case study of the Australian National Electricity Market (NEM) with different PV penetrations
- Findings and policy implications





## Challenges in the electricity industry

- Increasing challenges for electricity industries worldwide
  - *Increasingly uncertain demand growth (or no growth?).*
  - *Energy security concerns – due to high dependence on fossil-fuels (exposed to fuel price uncertainty and longer-term availability).*
  - *Environmental sustainability – the electricity sector is the largest single contributor to global CO<sub>2</sub> emissions (≈ 40%) (IEA, 2012)*

### **Implications for generation investment decision-making**

- Need to consider multiple objectives (yet potentially conflicting) in order to choose options that minimise:
  - **Industry generation costs**
  - **Cost risks** (due to future uncertainty in key cost factors such as demand growth, fuel prices, climate policies (i.e. carbon pricing).
  - **GHG emissions**
- Adding to the already complex nature of generation investment.

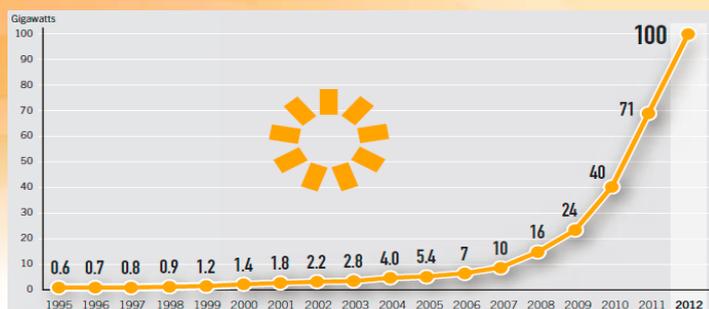
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3



## Role of solar PV in the electricity industry



Solar PV world  
generation capacity  
(REN 21, 2013)

- PV is one of the fastest growing RE technologies
  - *Rapid technological progress and cost reductions.*
  - *Potential to address energy security and climate change concerns.*
- But high PV penetration also have implications for the electricity industry operation and investment
  - *Unique technical and economic characteristics.*

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4



## Key policy question regarding PV

- What role might PV play in addressing energy security and environmental challenges facing the electricity industry?
  - *Given highly uncertain future*
  - *Zero fuel costs and no 'direct' emissions (therefore not subject to future uncertainty in fuel prices and availability as well as future carbon price).*
  
- Using a novel probabilistic generation portfolio modelling tool, this research provides a quantitative assessment to explore:
  - *The impact of high PV penetration of the overall industry costs, risks and emissions.*
  - *The value of large-scale PV in mitigating the impact of future uncertainty.*
  - *The interaction between carbon pricing and the value of PV generation.*
  - *Consider the Australian National Electricity Market (NEM) case study.*

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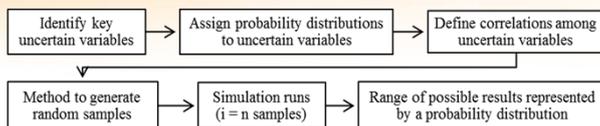
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5

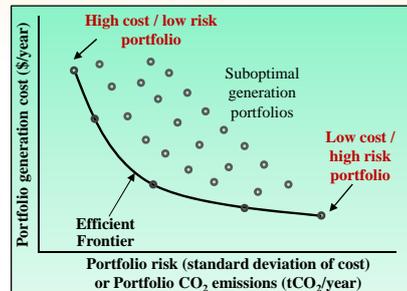


## Probabilistic Generation Portfolio Analysis

- A modeling tool to assess future generation portfolios given a range of uncertainties and multiple criteria (cost, costs risks and emissions)
- Combining 'Load duration curve (LDC) optimal mix' concepts with *Monte Carlo Simulation (MCS)* and 'portfolio analysis' techniques
  - *Using MCS to incorporate uncertainties when calculating costs (\$/year) and emissions (tCO<sub>2</sub>/year) for each generation portfolio mix.*



- *Apply portfolio technique to determine an **Efficient Frontier** of expected costs, cost risks (standard deviation of costs) for different generation portfolios.*



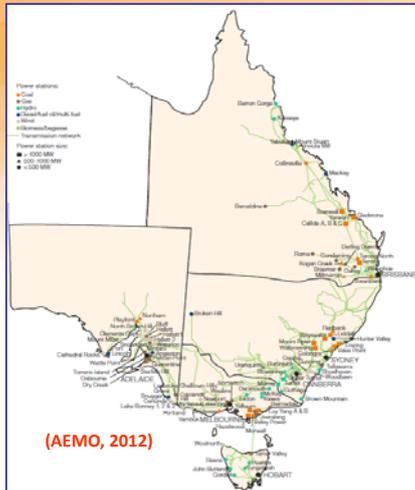
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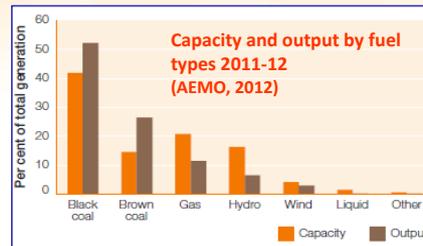
6



## The Australian NEM case study - Background



- Australian National Electricity Market (NEM) covers all Eastern States – 90% of electricity demand
- Generation mix consist largely of coal, with some gas, wind and hydro.



- Carbon pricing introduced on 1<sup>st</sup> July 2012
  - *Investment shift from coal to low-emitting sources (gas and RE)*

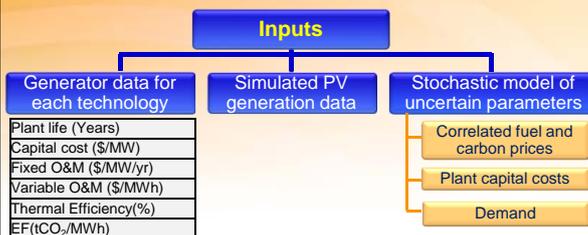
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7

## The Australian NEM case study

- Assume brown & black coal, CCGT, OCGT and PV generation options
- Uncertain future fuel and carbon prices, demand and capital costs.



- Using actual hourly demand.
- Fuel costs and new-build capital costs in 2030.
- Hourly simulated PV outputs in different locations
- Consider different PV penetrations and expected carbon price for a range of generation portfolios.

- Overall cost and CO<sub>2</sub> emission of each generation portfolio is calculated for 10,000 simulated fuel prices, carbon price, plant capital costs and electricity demand.
- Annual portfolio generation cost (\$) = Annualised fixed Cost + Variable Cost
- Variable cost consists of O&M, fuel and carbon costs
  - *Amount of energy generated by each technology is determined based on merit order dispatch in each period.*

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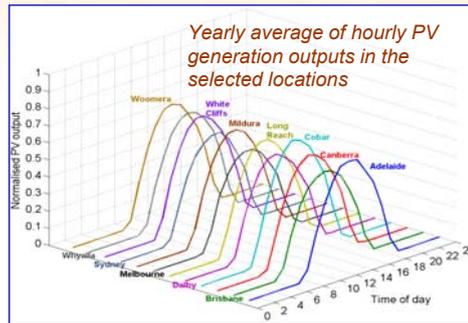
8



## Incorporating PV generation



- Model hourly PV outputs in different locations (major cities & regional areas) based on 1-MW fixed flat plate
  - Using actual weather data in 2010.
  - Scale the outputs for different PV penetration levels.
  - High-level transmission cost estimates are included for PV plants in regional areas.



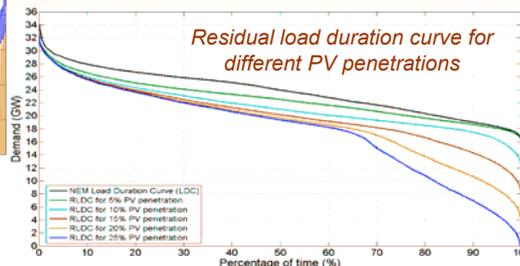
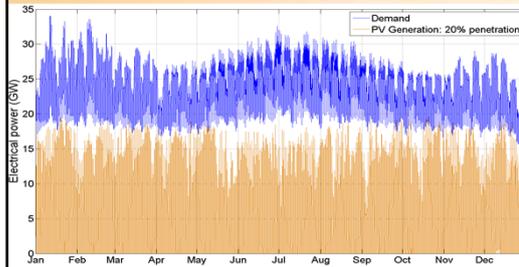
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## Incorporating PV generation

- Using 'Residual' (net) load duration curve (RLDC) method
  - Assuming priority dispatch for PV (dispatch when available)
- Net demand (after accounting for PV) is to be served by conventional generation technologies



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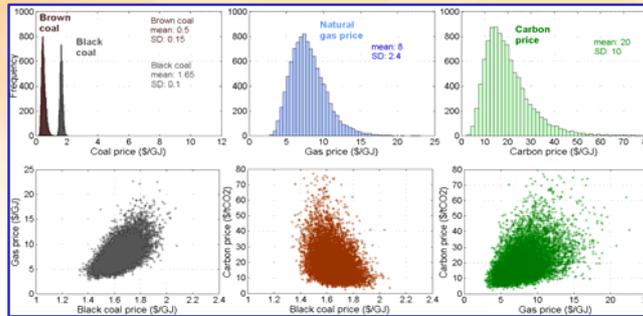




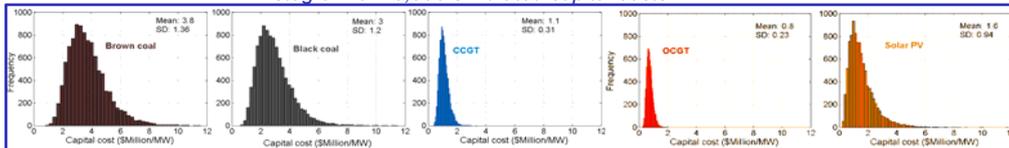
# Modelling uncertainties

- 10,000 simulated fuel & carbon prices, demand and plant capital costs
- Using lognormal distribution to characterise fuel prices, carbon price and capital cost uncertainties

Histogram of 10,000 simulated fuel & carbon prices

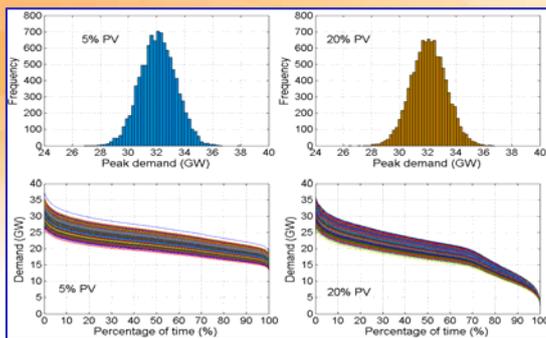


Histogram of 10,000 simulated capital costs

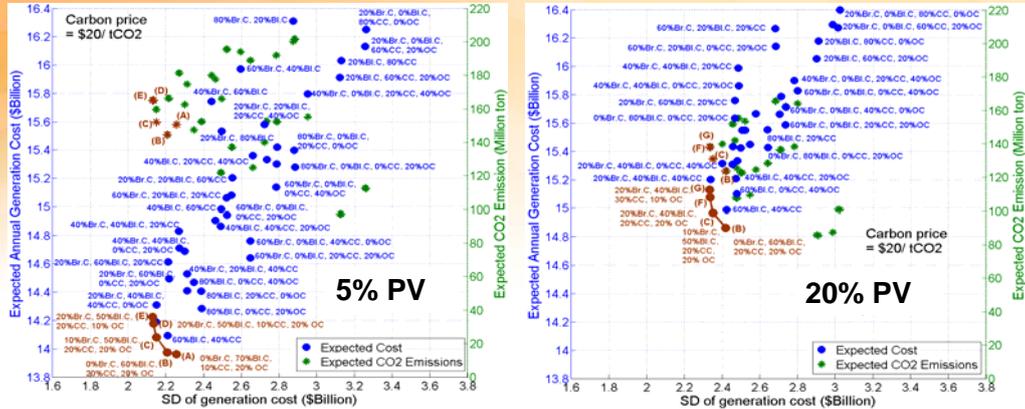


# Modelling uncertainties

- Demand uncertainty is modelled as variations in residual load duration curve for each PV penetration
- Each RLDC is derived for each sample of residual peak demand
  - Using normal distribution to characterise demand uncertainty.



## Portfolio costs, cost risks and CO<sub>2</sub> emissions



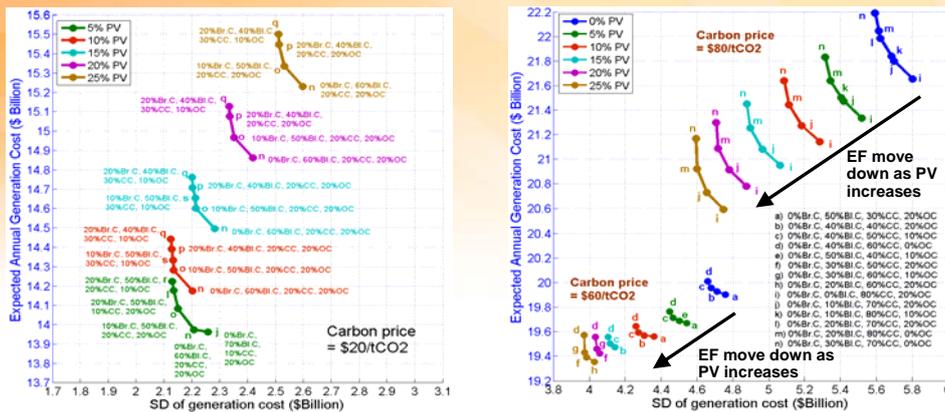
- Efficient frontier (EF) containing optimal generation portfolios - along EF generation cost cannot be reduced without increasing 'cost risk' (SD of cost)
- For a moderate carbon price – higher PV increases cost and cost risk but CO<sub>2</sub> emissions can be reduced quite substantially

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13

## Impact of carbon price and PV penetration



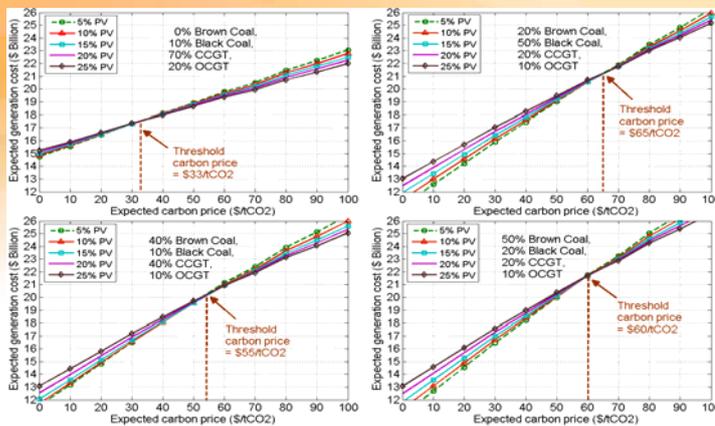
- For a low carbon price (i.e. \$20/tCO<sub>2</sub>), the optimal portfolios consist mainly of coal (brown and/or black coal)
- For higher carbon prices (> 50/tCO<sub>2</sub>), increasing the share of PV can reduce to overall costs and cost risks (EFs shift diagonally downwards)

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14

## Impact of carbon price and PV penetration



- Increased share of PV result in **higher fixed (capital) cost** but **less variable operating cost**

- Generally leads to *increased overall portfolio costs (since the proportion of fixed cost > variable costs)*
- *But the increases become smaller as carbon price goes up.*

- At a **“threshold”** carbon price – portfolio costs begin to decrease with higher PV
  - *As carbon price increases, the reduction in variable operating costs become more dominantly and eventually outweighs the increase in fixed cost .*
  - *The level of threshold carbon price depends of the technology mix.*

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15

## Findings and policy implications

- Large-scale PV generation can play a valuable role in hedging against fuel and carbon price uncertainty.
  - *Subsequently reduces the risk of generation portfolios (a real value to this risk reduction isn't often appreciated)*
- The economic value of PV generation is primarily influenced by the level of carbon price and the mix of generation technologies
  - *With sufficient carbon price, PV can reduce the overall industry costs, associated cost risks (in addition to greenhouse gas emissions).*
  - *The level of carbon price required for PV to reduce industry costs is modest compared with those modelled by the Australian Treasury or IEA modelling of price required to address climate change.*
- Findings highly relevant for energy and climate policy decision-making in the electricity industry
  - *Relating with large-scale PV generation and carbon pricing.*

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16

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## Current work

- ARENA funded project to explore *investment and policy support frameworks for facilitating high RE penetrations in Australia's EI*
  - *Extending and applying the modelling tool to analyse different policy options and scenarios including DSP, RETs etc.*
  - *Identifying opportunities and challenges for driving investment and facilitating the integration of RE into future generation portfolios.*
- Applying the modelling tool to analyse
  - *Explore options (technical and policy) to maximise synergies among RE and other emerging technologies such as EVs and energy storage*
  - *Revenue and profit of generators in the NEM*
  - *The impact of gas price uncertainty on future generation portfolios in the NEM*

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18



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