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Assessing the Potential Role of Large-Scale PV Generation and Electric Vehicles in Future Low Carbon Electricity Industries

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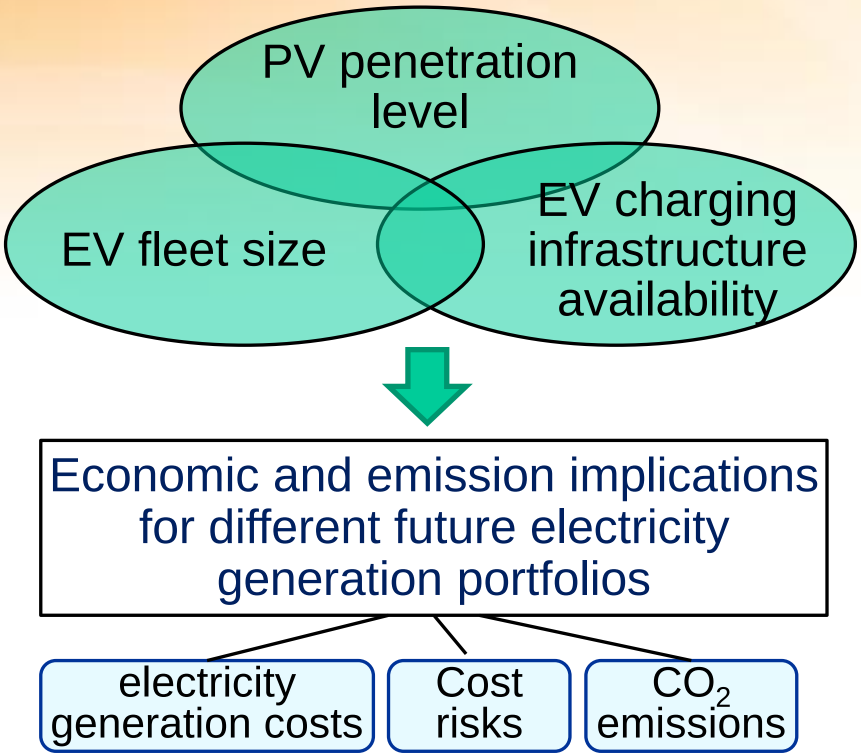
Objectives of the Study

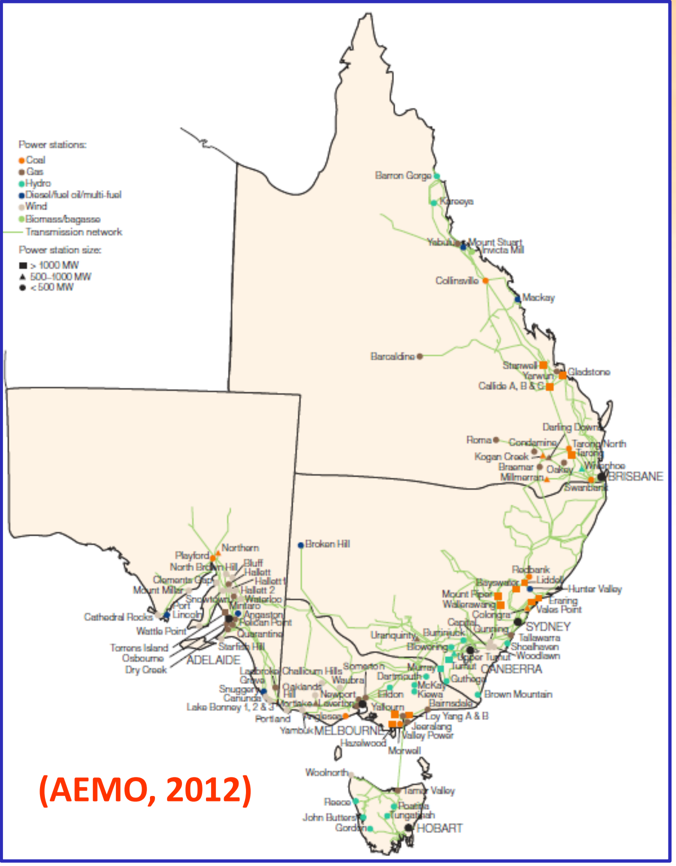
- Assessing potential *economic implications* of *large-scale PV investment* and *Electric Vehicles (EVs) uptake* in the broader context of the *Australian National Electricity Market (NEM)*
  - *In the context of generation investment given high future uncertainty*



- Implementing measures to facilitate the integration of both PV and EVs in the electricity industry

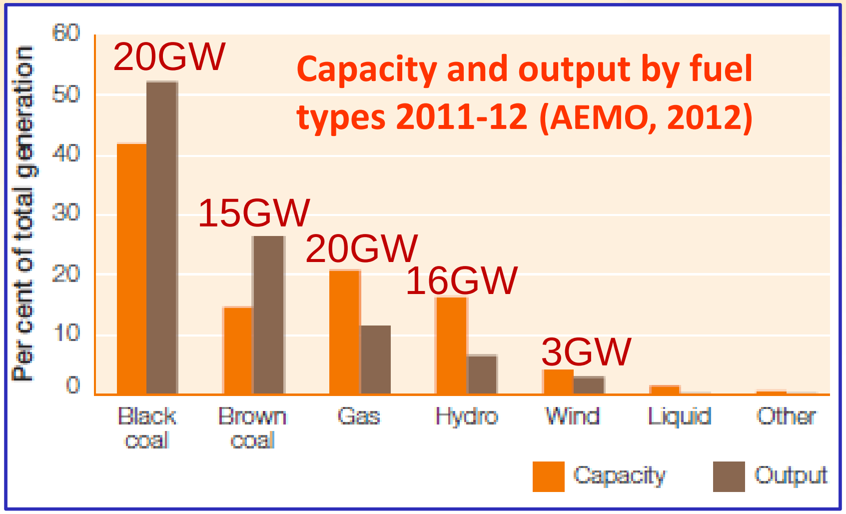
The Australian NEM

- Australian National Electricity Market (NEM) covers all Eastern States – 90% of electricity demand.



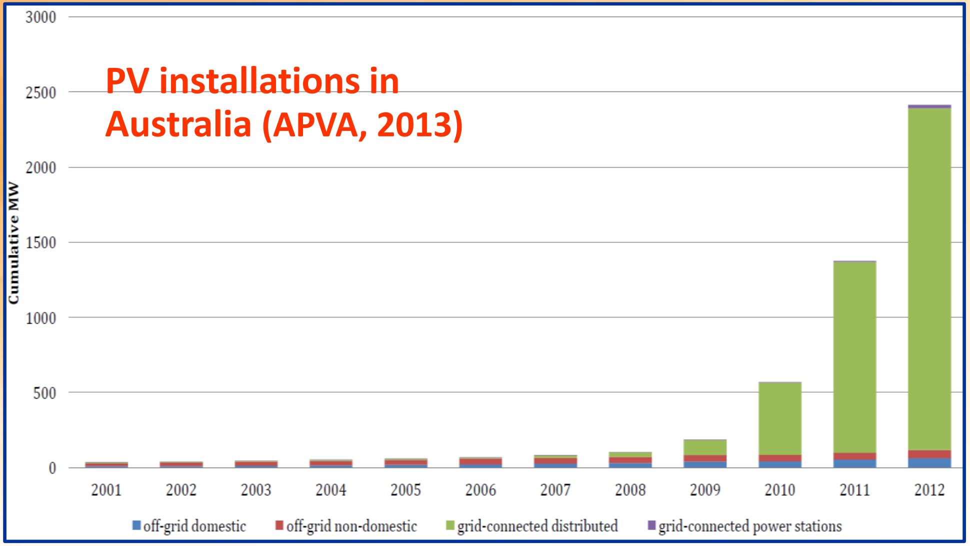
(AEMO, 2012)

Installed cap:
48 GW
Peak demand:
31 GW
Annual energy:
200 TWh

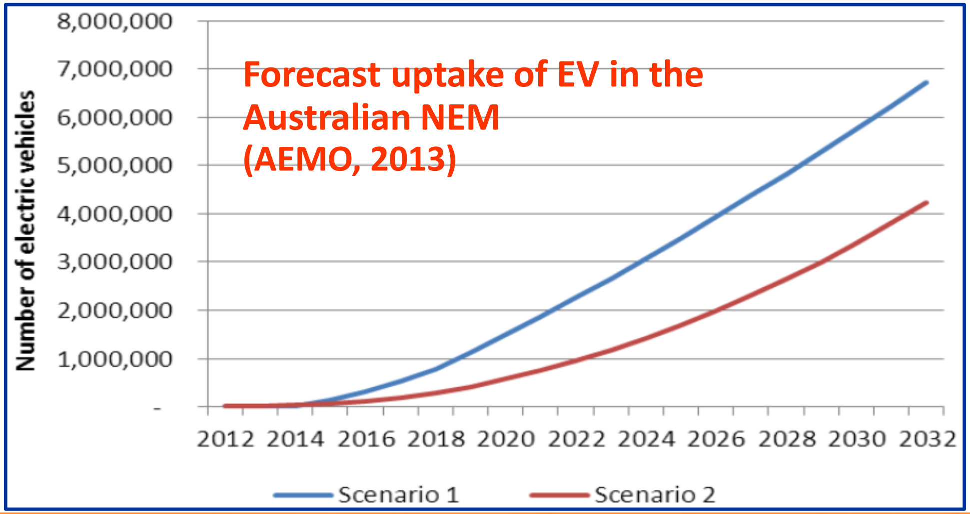


- Generation mix consist largely of coal (~70%), some Gas, Wind and hydro.
- Accumulated PV installation is around 2.5 GW and could grow to as high as 35 GW by 2030.

Solar PV and Electric Vehicles



- PV is one of the fastest growing renewable technologies
  - *Rapid technological progress and cost reductions.*
  - *Renewable energy and climate policies – e.g. FiT, Renewable Energy Targets (RETs)*



- Plug-in EVs are emerging as significant elements of future vehicle fleet :
  - *Major cost reductions*
  - *Concerns over future petroleum availability and prices as well as climate change.*

Integrating PV and EV into the Electricity Sector

Supply side		Demand side
PV		**EV**
Variable and unpredictable (partially)	⟷	Flexibility of charging load
Non-storable	⟷	Aggregated storage capacity
Zero operating emissions	⟷	Increase elec. demand and emissions

Potential synergies between PV and EVs

- Potential to facilitate integration of both PV and EVs into future electricity industries at high penetration level

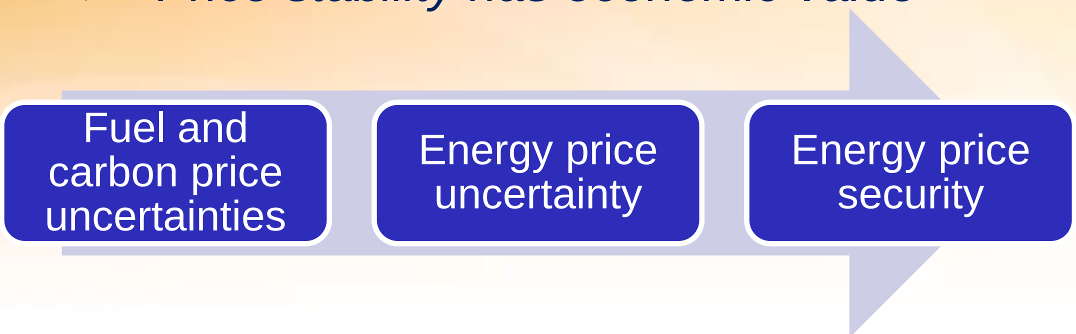
But there are potential challenges

- Different technical and economic characteristics to conventional generation technologies and end-user load
- Significant uptake of both PV and EV can have *operating* and *economic implications* for future electricity industries

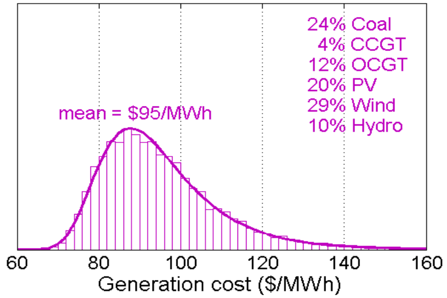
This study focuses on economic implications relating with future generation investment in the context of high future uncertainty.

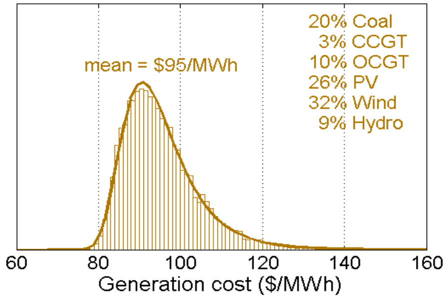
Uncertainties in generation investment

- Significant uncertainty around future fossil-fuel prices, carbon pricing policies and electricity demand growth in many electricity industries.
- Uncertainties in fuel & carbon prices have implications for energy security
  - *Price stability has economic value*



- ***Risk*** – *arise* due to *many possible outcomes* as a result of uncertainty.
  - *The likelihood of loss or unexpected high costs.*





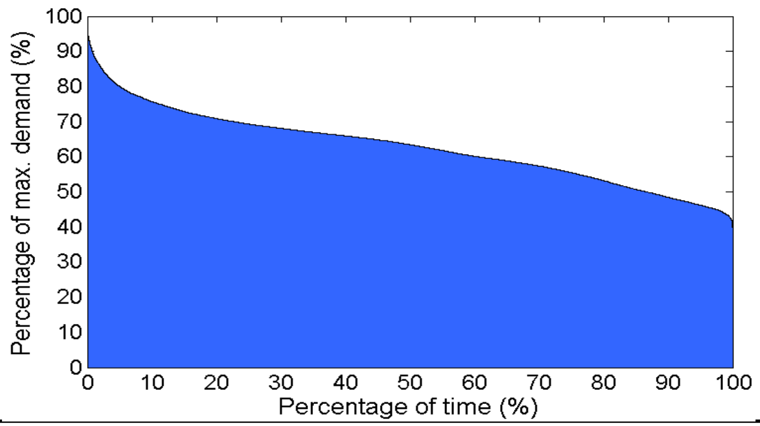
Risks can be quantified by spread of possible outcomes (e.g. standard deviation)

- Investment in a certain generation option (or portfolios) can result in exposure to external price risk

Probabilistic Generation Portfolio Modeling

- A modeling tool to assess a large number of future generation portfolios given a range of uncertainties taking into account PV and EV.

Load duration curve



MCS process

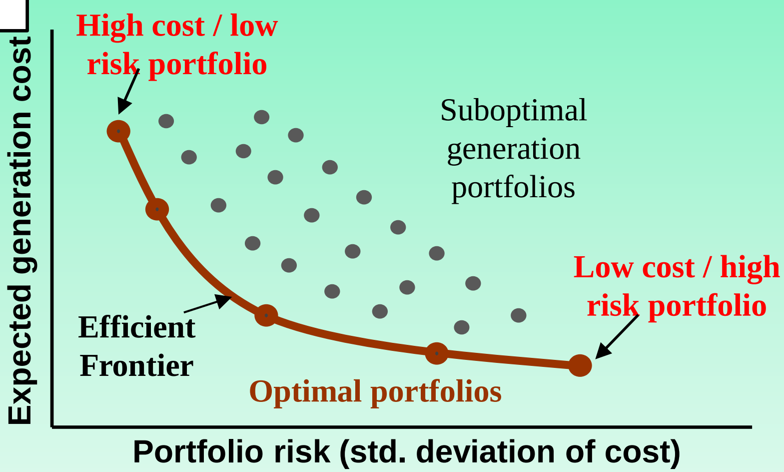
Identify key uncertain variables → Assign probability distributions to the uncertain variables → Generate random samples (i = n samples) → Calculate total costs and emissions → Range of possible results represented by a probability distribution

Mean and SD can be used to measure expected cost and risk profile

Generation Portfolio Analysis

Expected (mean) cost and *cost spread (SD)* of each portfolio is plotted to compare tradeoff between ***costs*** VS ***risks***.

Optimal generation portfolios fall along ***"Efficient Frontier"*** *(Costs can only be reduced by accepting higher cost risks).*



Modeling Generation Investment Scenarios

Inputs

- **Generator data of each technology** — AETA (BREE)
- **Hourly demand, PV generation, EV charging load** — EV modeling, PV modeling
- **Prob. dist. of fuel prices, carbon price, demand** — Estimated from AETA (BREE)

- Four new generation options: ***Black coal, CCGT, OCGT and PV (utility scale).***
- Cost parameters in 2030.
- Uncertain future ***fuel and carbon prices***, ***demand*** and new-build ***plant capital costs***.

- Consider different cases of PV penetrations, EV fleet sizes, EV charging infrastructure availability and expected carbon prices.

PV penetration	EV fleet size	EV Charging infrastructure	Expected carbon price
0% - 25% in 5% interval	*0%, 20%, 50%*	*- Residential - Universal*	*\$0, \$20, \$50 and \$80/tCO_2*

Determine optimal generation portfolios for each case

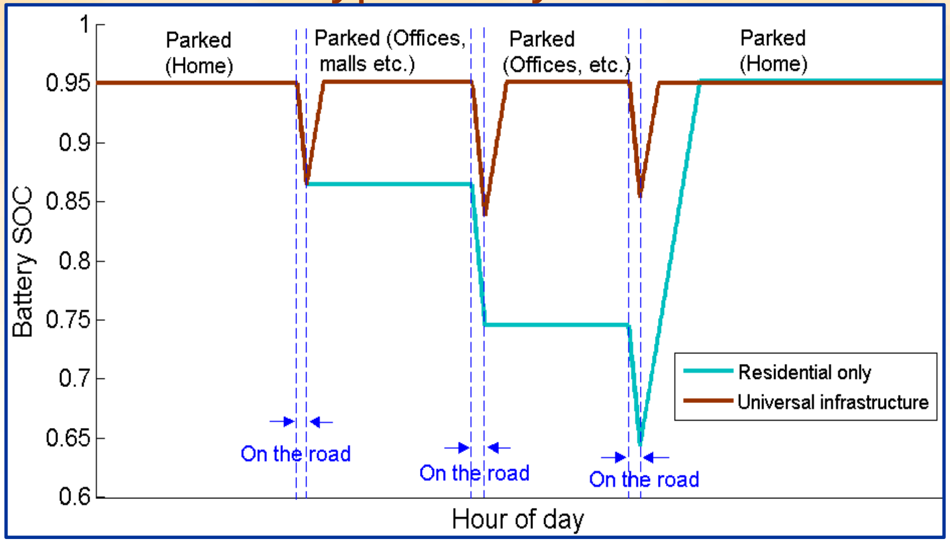
- Determine overall generation costs, cost risks and CO_2 emissions for different possible thermal generation portfolios

Electric Vehicle Modeling

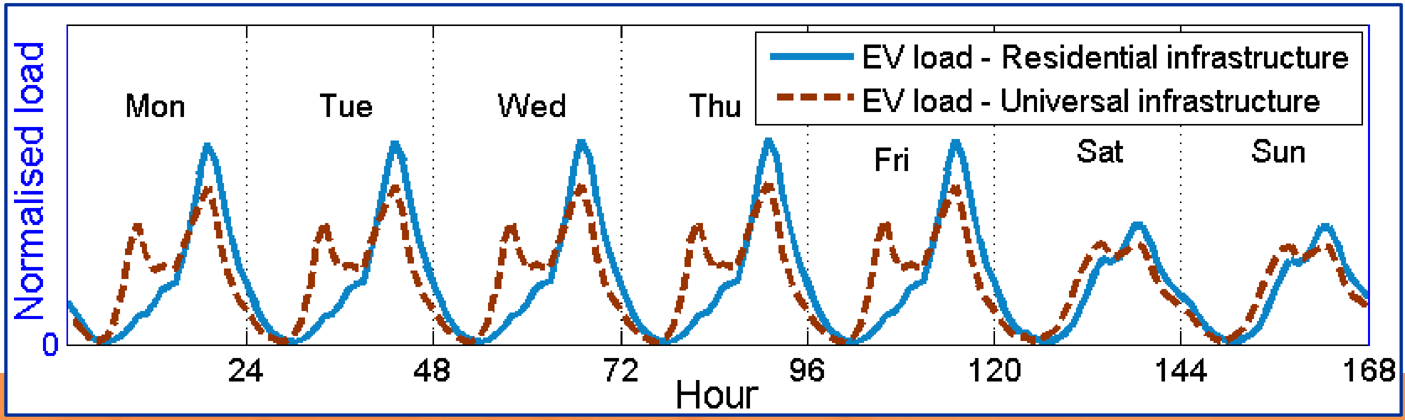
Charging Infrastructure Availability
- Residential only
- Universal

- Simulate EV load for two charging infrastructure scenarios based on
  - *Survey of vehicle use patterns*
  - *A time based simulation to establish the Battery State of charge*

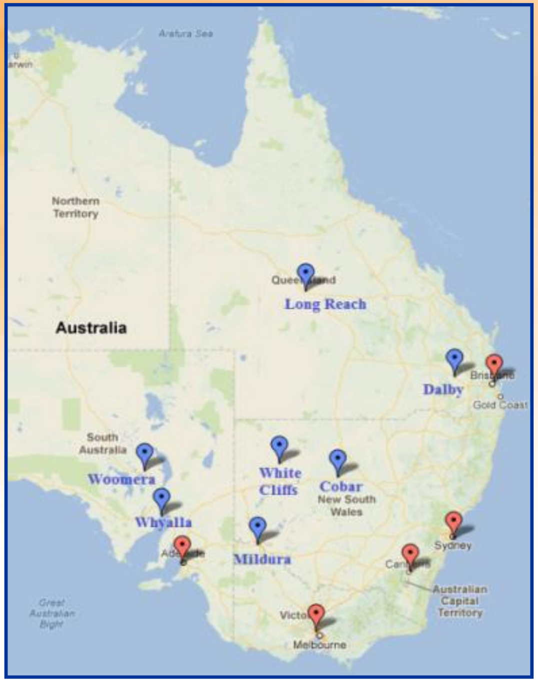
Battery state of charge (SOC) during a typical day



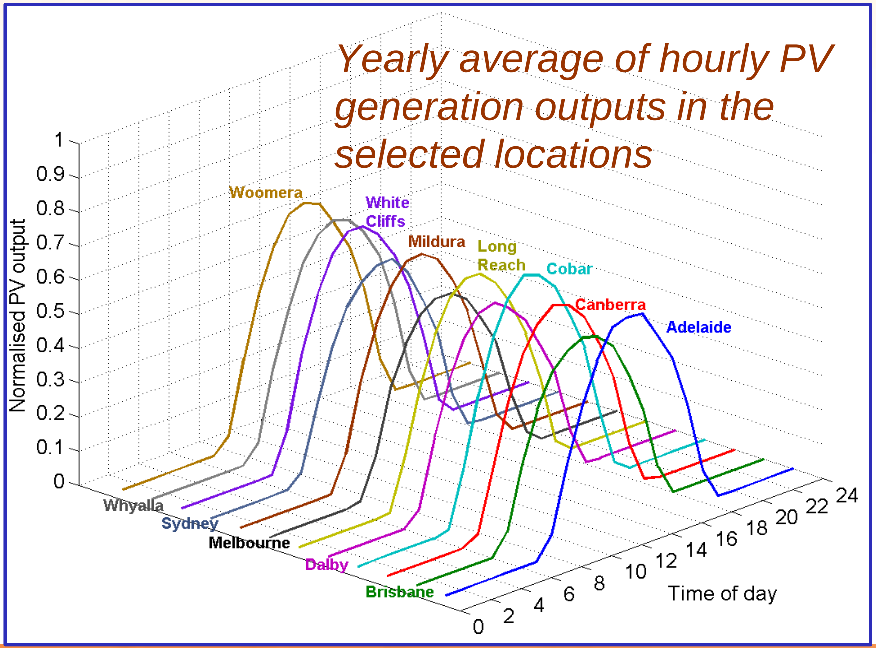
EV charging load in a typical week



PV Generation Modeling



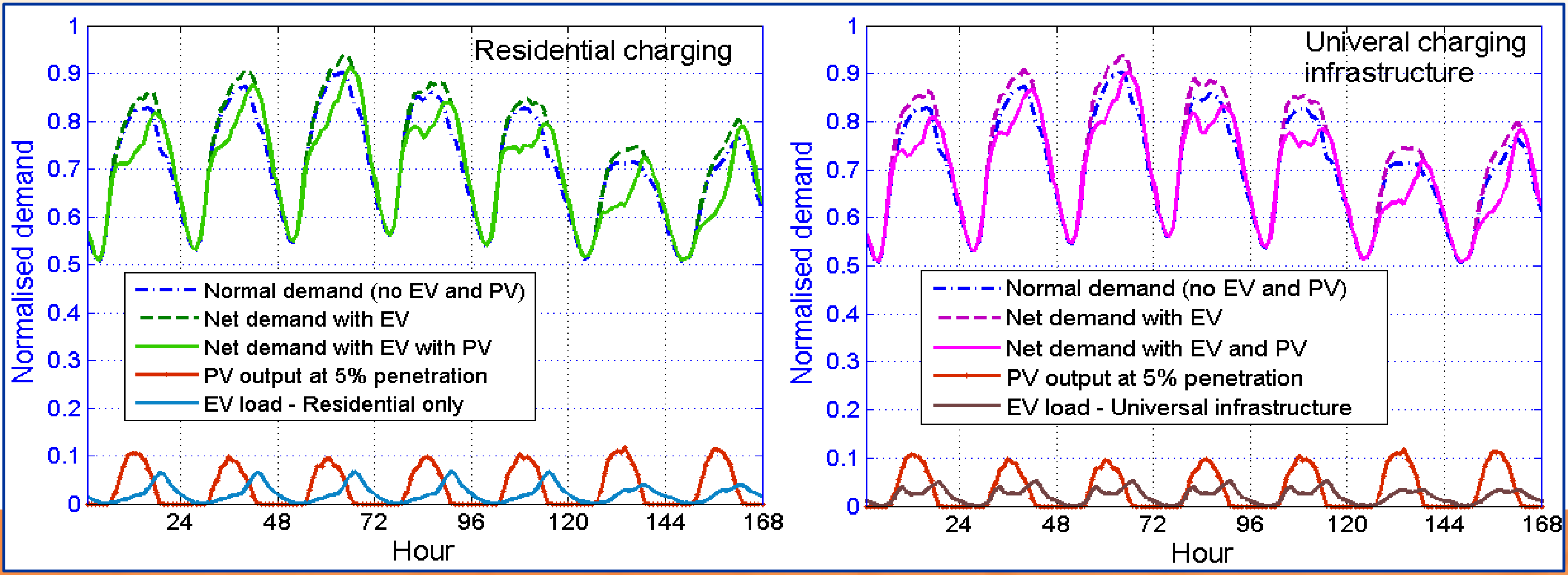
- Model hourly PV outputs in different locations (major cities & regional areas) based on 1-MW fixed flat plate
  - *Using actual hourly weather data.*
  - *Scale PV outputs for different penetration levels.*
  - *High-level transmission cost estimates are included for PV plants in regional areas.*



Incorporating PV and EV

- Using Residual (net) Load Durative Curve techniques
- Scale PV and EV outputs for different penetration levels
- Assume priority dispatch for PV - *Treat as negative demand*
- Simulate hourly EV charging load is then added to produce net demand

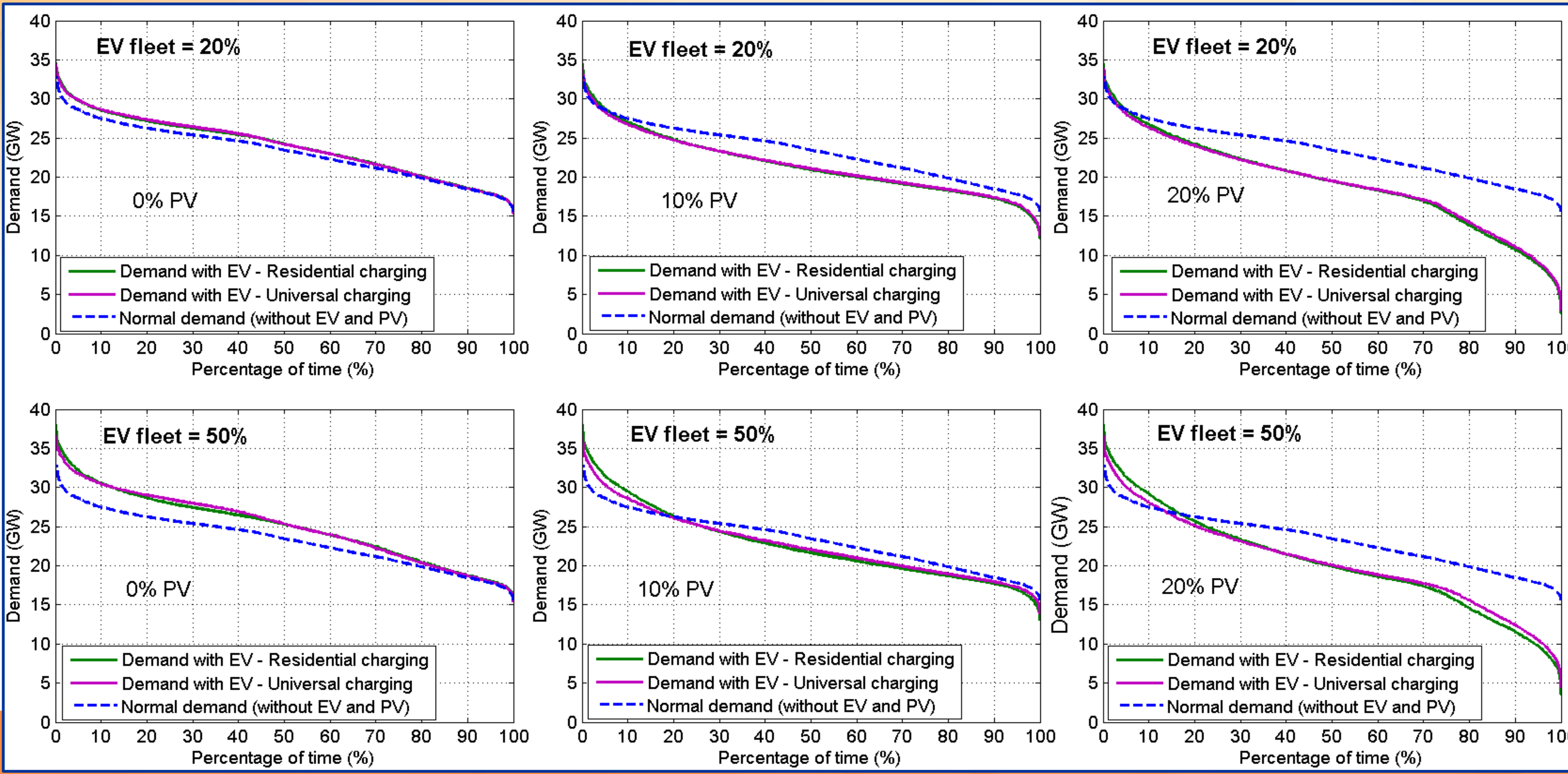
Net hourly demand = Electricity demand − PV generation + EV charging load



Residual Load Duration Curve

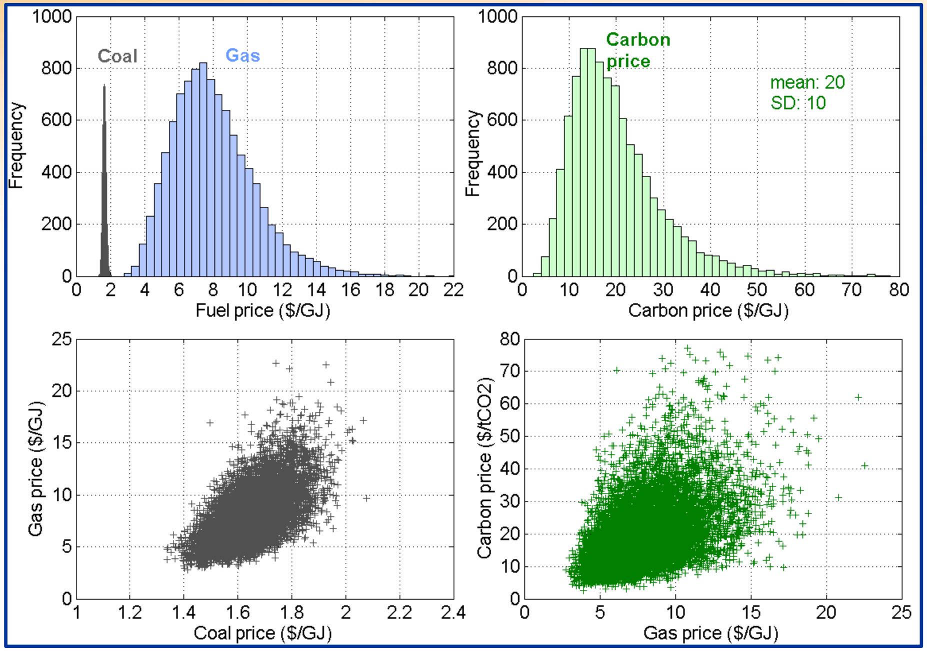
- RLDC is served by conventional generation technologies in the portfolio.
  - *Merit order dispatch in each period of the RLDC*

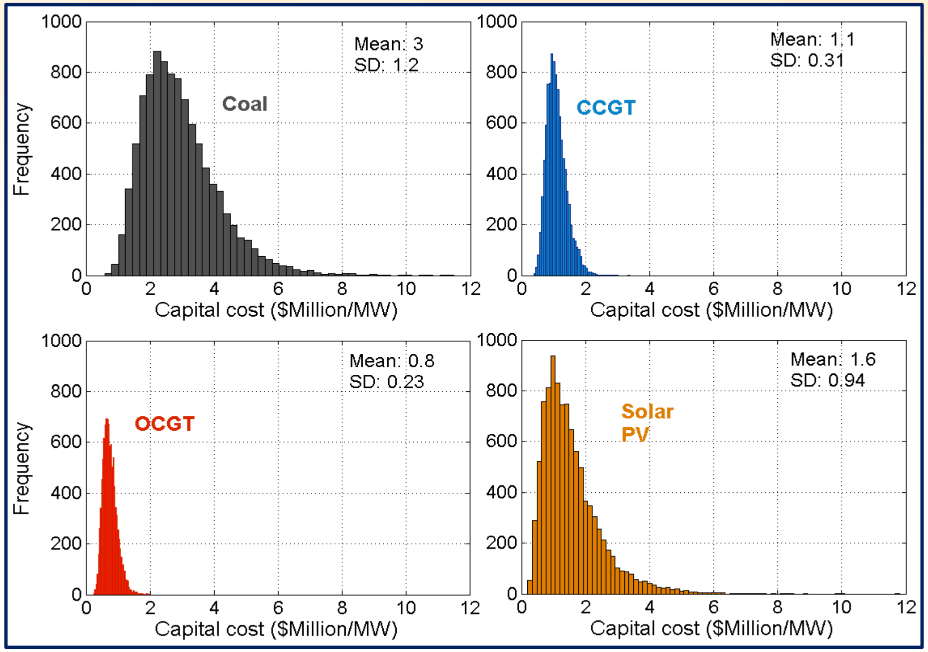
Some examples of RLDC for different PV and EV penetrations



Modeling uncertainties

- Lognormal dist. is applied to future gas & carbon price and capital cost.
- A normal distribution for electricity demand.
- SDs of each uncertain parameters are estimated based on the spread between low and high projections.

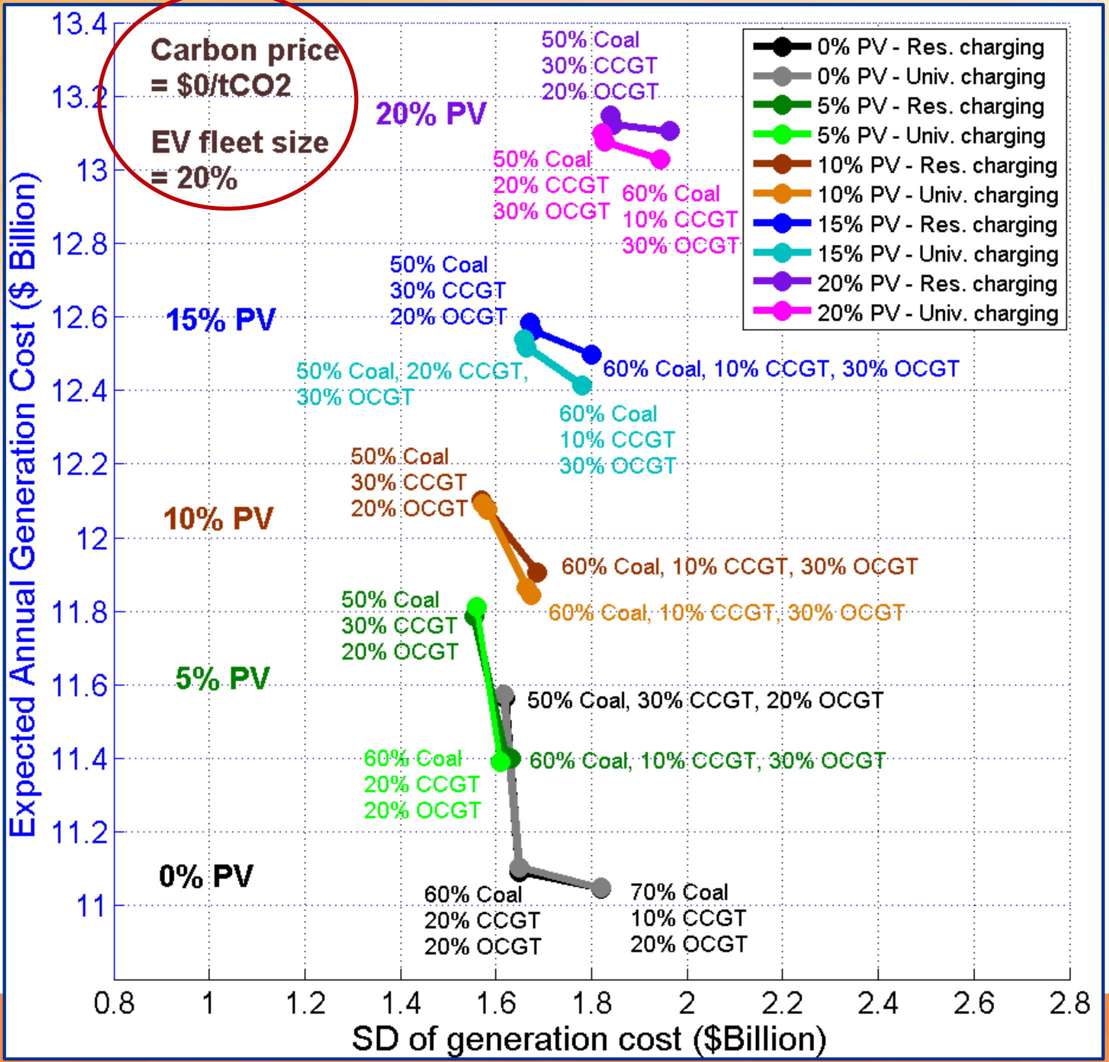




Histogram of gas price, carbon price and demand over 10,000 simulations

Optimal Generation Portfolios

'Efficient Frontier' (EF) (without a carbon price)



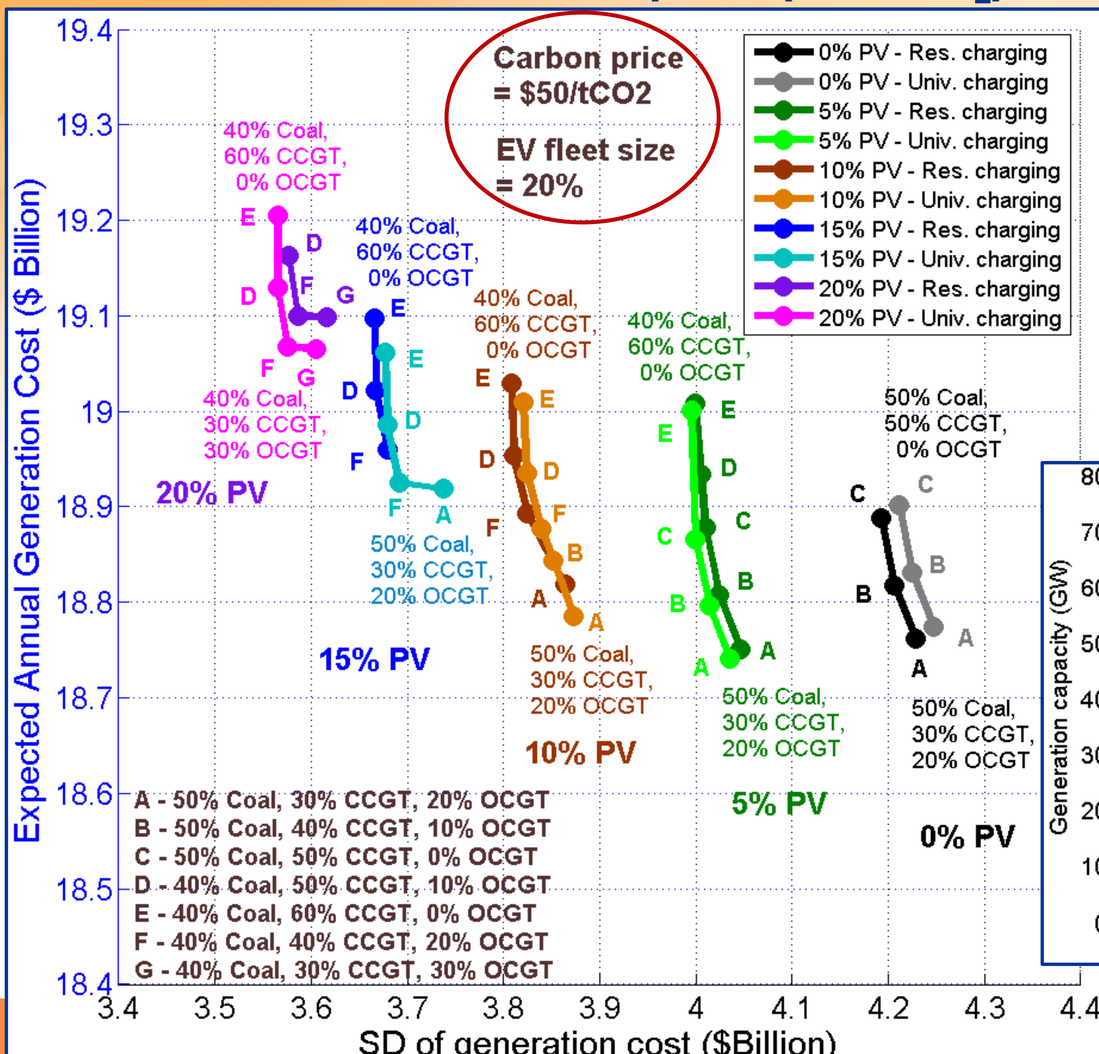
Expected cost (mean) and *cost risk (SD of cost)* of each generation portfolio are plotted.

Without a carbon price and a certain EV fleet size (20%)

- Optimal portfolios contain mainly of coal.
- Higher PV penetration increases both the *overall cost* and *cost risk.*
- Overall generation costs for the case of universal charging infrastructure are lower than Residential charging.
  - *Cost difference more apparent as PV penetration increases*

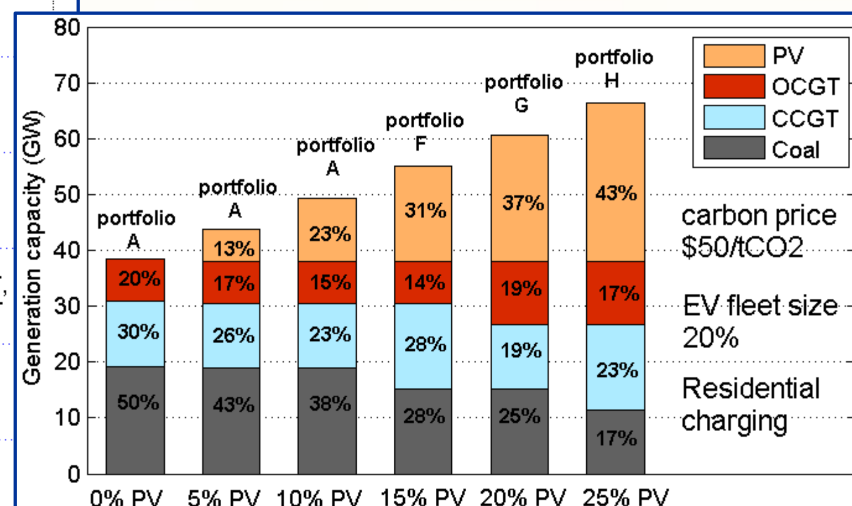
Optimal Generation Portfolios

EFs for a moderate carbon price ($50/tCO$_2$)

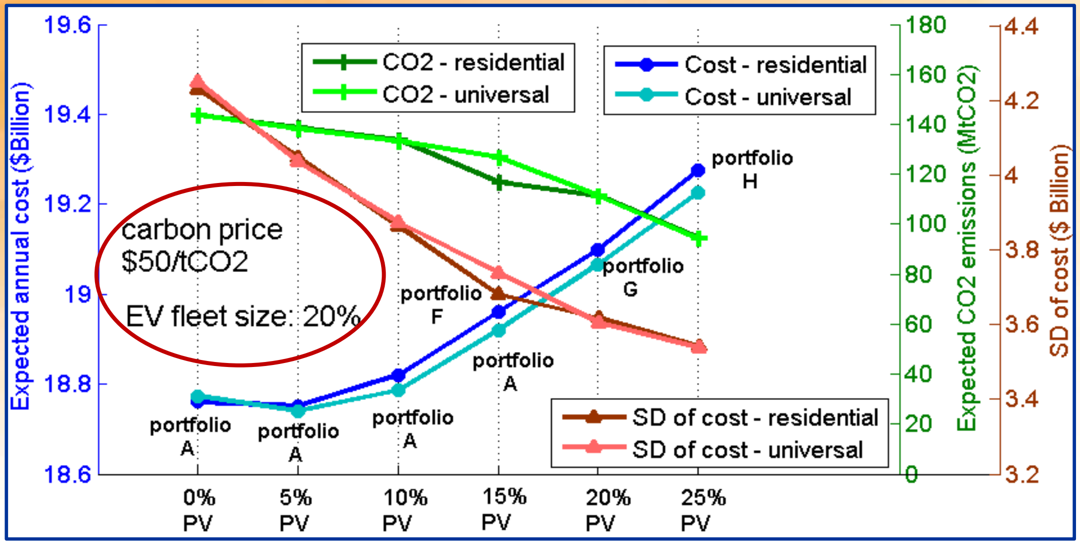


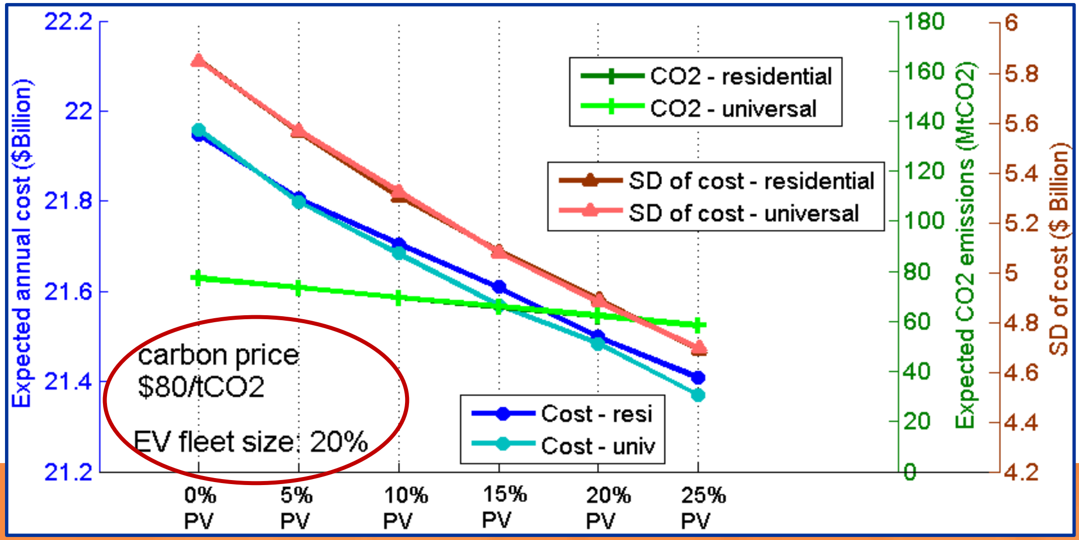
With a moderate carbon price and a certain EV fleet size

- Optimal portfolios contain less coal and more gas.
- Higher PV penetration increases the *overall cost* but lower *cost risk* (lower SD)



Implications of PV penetration, charging infrastructure and carbon price





'Least cost' portfolios for each PV penetration

- ***Expected cost,***
- ***cost risk ,***
- ***CO_2 emissions***

With higher carbon price (e.g. $80/tCO$_2$)

- Overall costs decline significantly with higher PV penetration (in addition to cost risk and CO_2 emissions)
- Costs for universal EV charging infrastructure are still lower than residential only charging

Future PV and EVs Integration

- Economic potential to integrate both PV and EVs at high penetrations
  - *Value of PV generation in satisfying some of the additional demand for EV charging*
- Potential synergies between PV and EVs in reducing overall system costs, cost risks and CO_2 emissions
  - *Particularly in the context of high carbon pricing*
  - *RE and climate policies with regard to carbon pricing are important*
- Provision of *non-residential charging infrastructure* would provide an economic benefit
- Active management strategies for EV charging are still required to achieve maximum value of high PV and EV penetrations
  - *EV control charging to manage EV charging load pattern*

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