Managing Low Carbon Technology Options in the Electricity Sector: A Case Study of Guangdong Province in China

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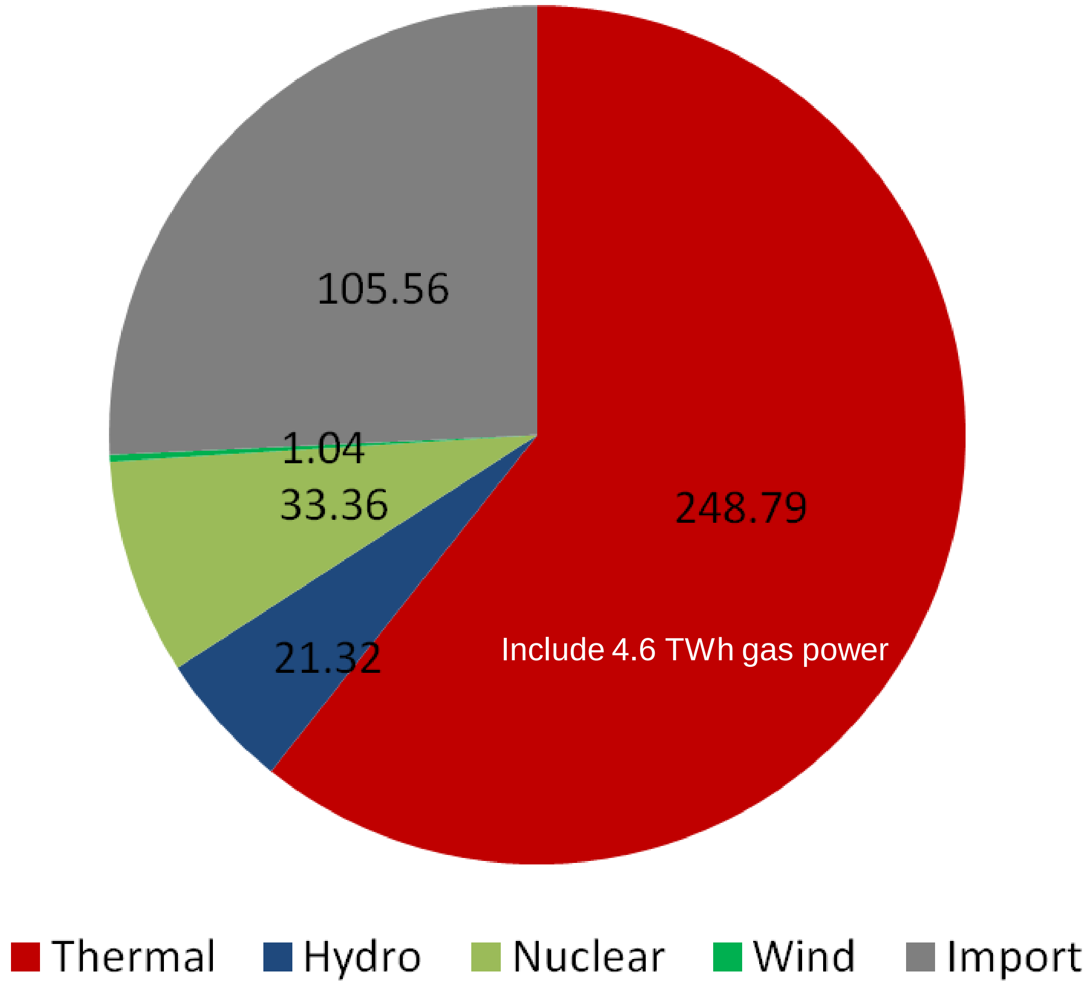
Guangdong Province in China

Guangdong versus UK

	Guangdong	United Kingdom
Population (million)	104	61
Land Area (thousand km^2)	180	245
GDP per capita in 2010	US$11210	US$ 35860
Total Electricity Demand in 2010	405 TWh	384 TWh
Low Carbon Policy	Pilot Low Carbon Province; 45% reduction in GDP carbon intensity from 2005 to 2020	80% greenhouse gas reduction by 2050

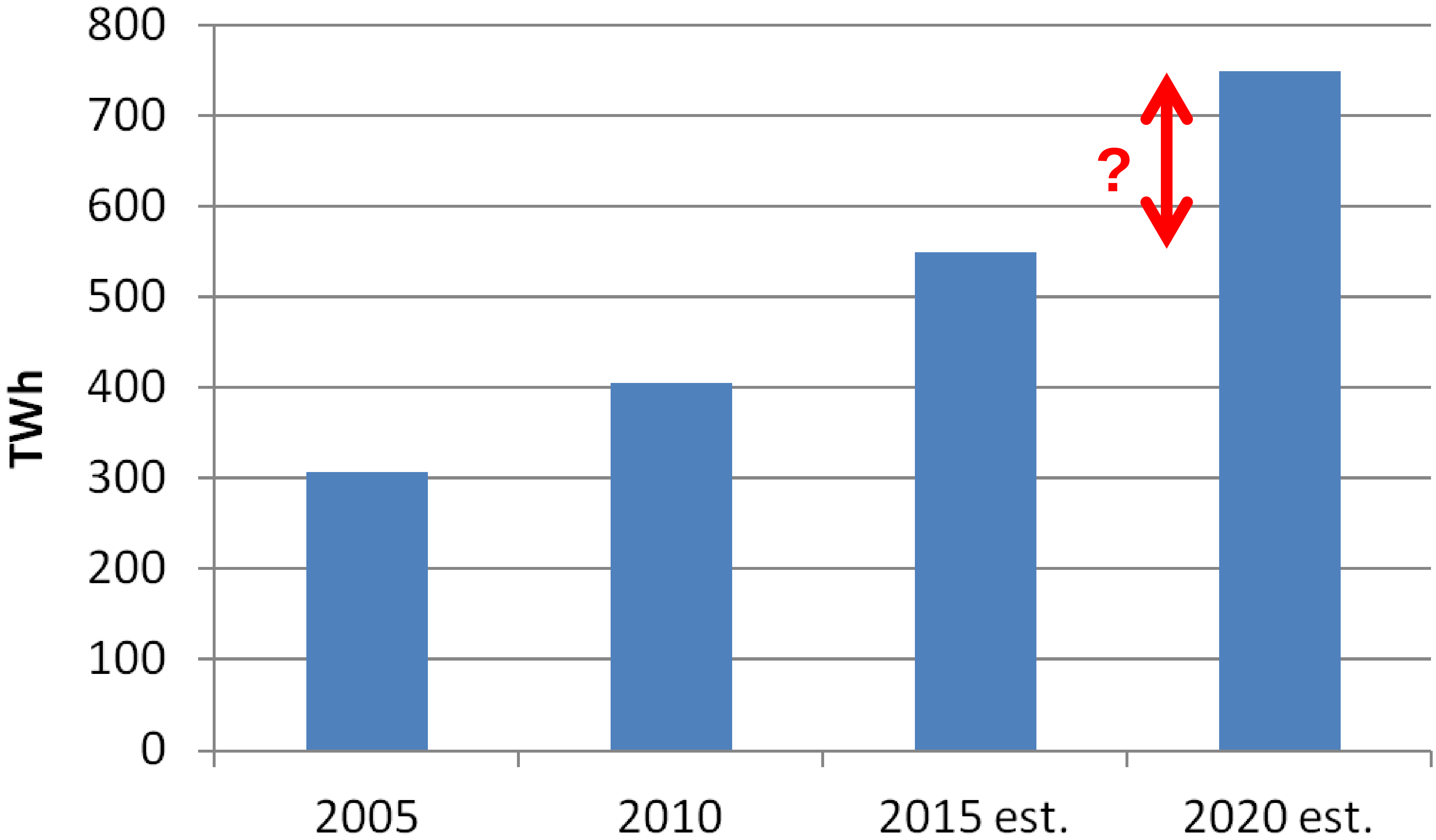
Source: IMF, 2009; DECC, 2011; China Statistic Annual Report 2011; The World Bank 2011;

Guangdong Electricity Generation by Type in 2010 (TWh)



Source: Guangdong Statistics Bureau, 2011

Historical and Projected Total Electricity Consumption in Guangdong



What is the economics of generation technologies portfolio in reducing greenhouse gas emissions and meeting the 200 TWh incremental electricity demand in Guangdong by 2020?

Uncertainties in the Energy System

- **Technology development** (e.g. global RD&D, experience curve)
- **Operational uncertainties** (e.g. technology failure, intermittency, flexibility of demand)
- **Infrastructure options** (e.g. power grids, pipeline)
- **Market risks** (e.g. carbon price, gas price, demand of electricity)
- **Timing of policy decisions** (e.g. technology lock-in)

The energy policy and investment options need to be evaluated at a strategic level through a portfolio approach.

Investment Flexibility

- At each decision point, investors / generators can exercise options in response to uncertainties.
- For example, closing down a coal-fired power plant early, retrofitting a gas plant to CCS, investing in a shorter lifetime renewable technology instead of nuclear

The option value of investment or policy decision needs to be taken into account, e.g. through a real option approach (ROA).

Applications of Energy Technology Portfolio Approach

- Investment decision at firm level

e.g. contract portfolio optimization (Yau et al, 2011)

- Energy planning at national level

e.g. the portfolio effect of incorporating new technologies: (Albrecht, 2007; Awerbuch et al, 2008; Munoz et al, 2009; Allan et al, 2011; Hart and Jacobson, 2011; Bhattacharya and Kojima, 2012)

Roques et al (2008)

study both fuel and electricity (Guerrero-Lemus, 2012)

Energy Planning (Arneano et al, 2012)

Diversity of technology (Doherty et al, 2008)

China's generation portfolio (Zhu and Fan, 2010)

Energy Technology Real Option Studies

- A firm’s investment decisions on new and unconventional technologies under market and technical uncertainties (Siddiqui and Fleten, 2010; Yang et al, 2009)

- The flexibility of upgrading in a CCS power plant (IEA GHG Study)

Two Major Challenges

- Measure Risks
- Understand ‘Correlations’ and ‘Flexibilities’

Major Steps

1. Define the distribution and correlation of uncertainties, the properties of flexibilities
2. Study the mean value and the risk of levelised cost of electricity in hypothetical energy portfolios through Monte Carlo simulation
3. Incorporate flexibility, intermittency, and operational and investment flexibilities in projects' lifetime for cost estimation
4. Take into account more uncertainties <u>(Future Work)</u>

Methodology for Estimating Electricity Portfolio Cost and Risk

- Portfolio Cost (C_p) is given by $$E(C_p) = \sum_i w_i E(C_i)$$

C_i is the random levelised cost of generation for technology i

w_i is the weight of technology i in the system

- Portfolio Risk (σ_p) is given by $$\sigma_p^2 = \sum_i \sum_j w_i w_j \sigma_i \sigma_j \rho_{ij}$$

σ_p is the standard deviation of portfolio generation cost,

σ_i is the standard deviation of levelised cost of electricity technology i

ρ_{ij} is the correlation of levelised costs between technology i and technology j

- Levelised cost of electricity (C)

$$C = \sum_{t}^{L} \frac{Q_t + F_t + O_t + A_t}{(1+d)^t}$$

Q_t is capital investment at year t

F_t is fuel cost at year t

O_t is the non-fuel O&M cost at year t

A_t is cost of emission at year t

d is the discount rate

L is the lifetime of the project

Flexibility Issues Considered in Model

- Incorporate the impact of intermittency and inflexible generation on total generation cost in the system, (based on discussion with Southern Grid) taken into account existing accounting method for wind power in the system (e.g. Delarue et al, 2011; Hart and Jacobson, 2011)

- ROA model for incorporating the option of retrofitting coal-fired power plants to CO2 capture in its lifetime (Liang and Li, 2012)

Technical and Financial Assumptions	CCGT	Coal Base load	FOAK Coal + CCS	Offshore Wind	Nuclear 3G PWR Reactor
Commissioning Period			2016-2020		
Baseline discount rate	9.0%	9.0%	13.0%	11.5%	12.5%
Planning	2	2	2	4	3
Construction period	3	3	4	2	4
Operating period	30	30	30	30	60
Gross Output (MW)	830	1023	1012	100	1016
Average Load factor	60%	85%	85%	30%	90%
Net Efficiency (HHV)	53%	41%	32%	95.60%	92%
CO2 emission factor (gram/kWh)	382	805	92	0	0
Capex (USD/kW)	465	700	1150	1500	1900
Fixed Opex (MW/yr)	8000	19000	39000	49000	72000
Variable Opex (million USD/MWh)	0.72	1.5	3.1	n/a	2.7
Fuel Price (USD/MWhtherm)	27	14.3	14.3	n/a	8.2
CO2 Emission Cost (USD/tCO2e), growth and volatility:		15 (2015), 6%, 16%			
CO2 Transport, storage and monitoring (USD/tCO2e)	n/a	n/a	19	n/a	n/a

Assumption of Price Correlation Matrix

	Coal	Gas	Nuclear Fuel	CO2
Coal	1			
Gas	0.75	1		
Nuclear Fuel	0.25	0.2	1	
CO2	0.6	0.9	0.1	1

Volatility assumption of individual cost component (std dev)

	CCGT	Coal Base load	FOAK Coal + CCS	Offshore Wind	Nuclear 3G PWR Reactor
Capital	6%	3%	10%	8%	6%
Fuel	15%	10%	10%	0%	5%
Non-fuel O&M	5%	5%	8%	0%	10%
CO2 emission	10%	5%	6%	0%	0%

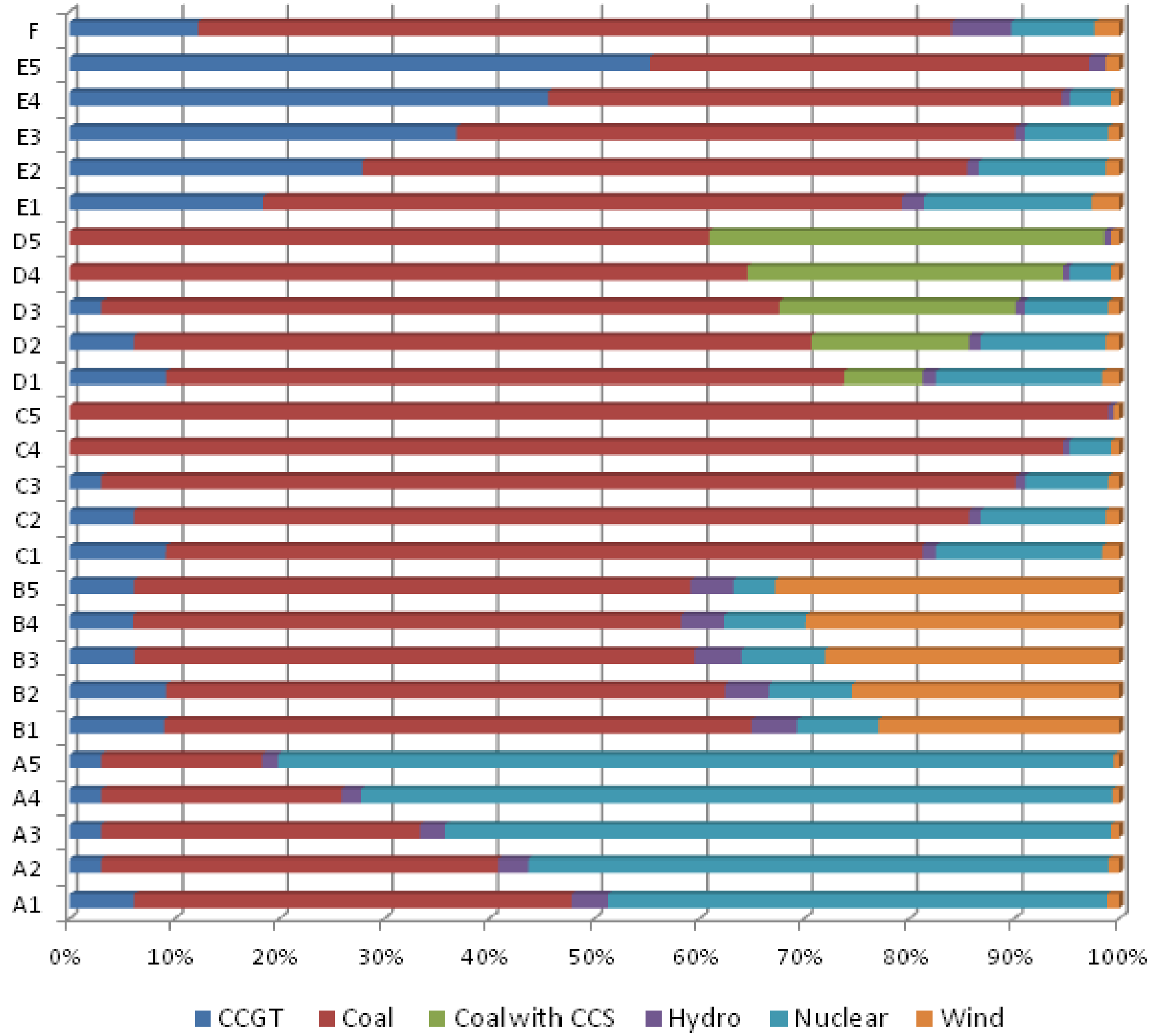
Weights of Each Components on Individual Technology Cost Volatility

	CCGT	Coal Base load	FOAK Coal + CCS	Offshore Wind	Nuclear 3G PWR Reactor
Capital	32%	43%	47%	69%	70%
Fuel	55%	41%	46%	0%	19%
Non-fuel O&M	4%	5%	4%	0%	10%
Wind Variance	0%	0%	0%	31%	0%
CO2 emission	5%	11%	3%	0%	0%

Theoretical Potential of Energy Generation Technologies in Guangdong from 2015 to 2020

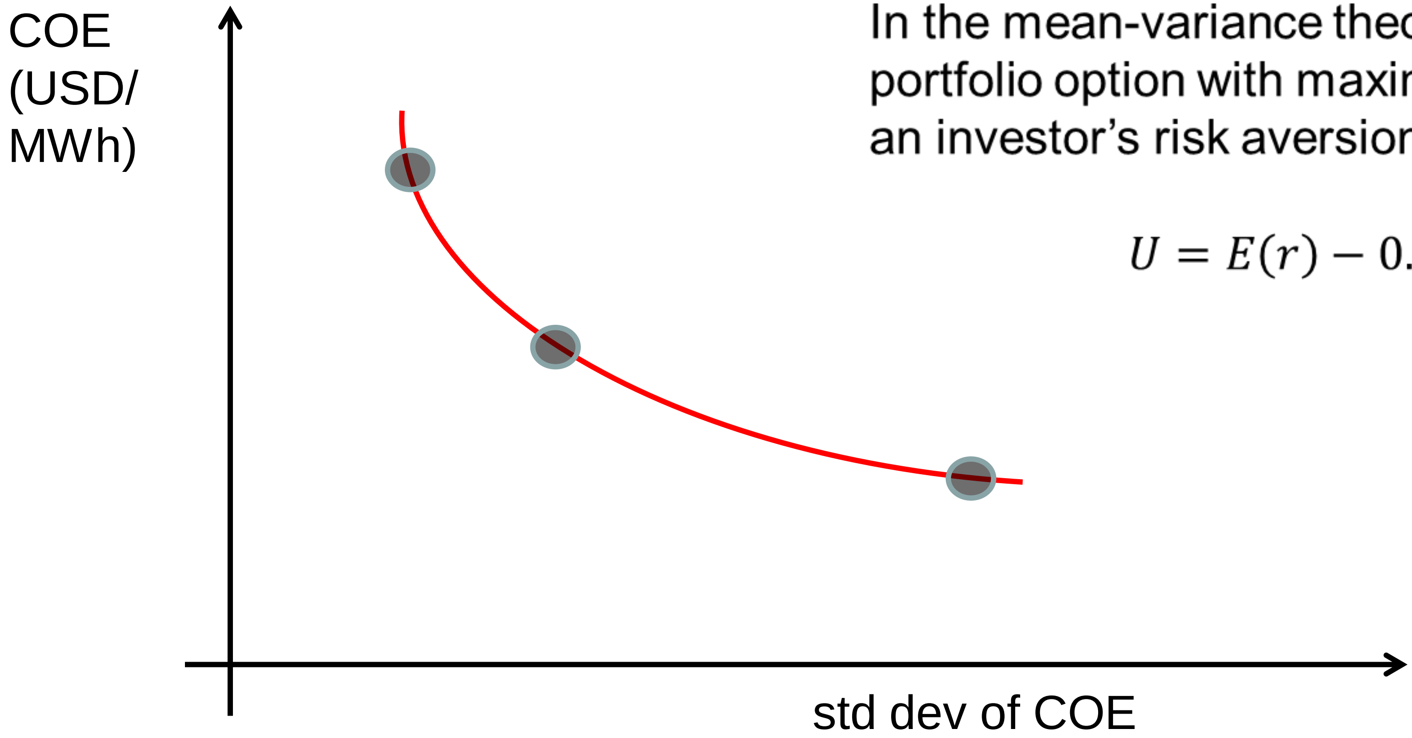
	GW	TWh pa
CCGT baseload	15	111.69
Pulversied coal baseload	30	223.38
Coal baseload with CCS	25	186.15
Hydro power	5	17.52
Nuclear	20	157.68
Offshore Wind	25	65.7

Definition of Hypothetical Portfolios



Portfolio	Characteristics
A1-A5	High Nuclear
B1-B5	High Offshore Wind
C1-C5	High Coal wo CCS
D1-D5	High Coal w CCS
E1-E5	High CCGT
F	Balanced Portfolio

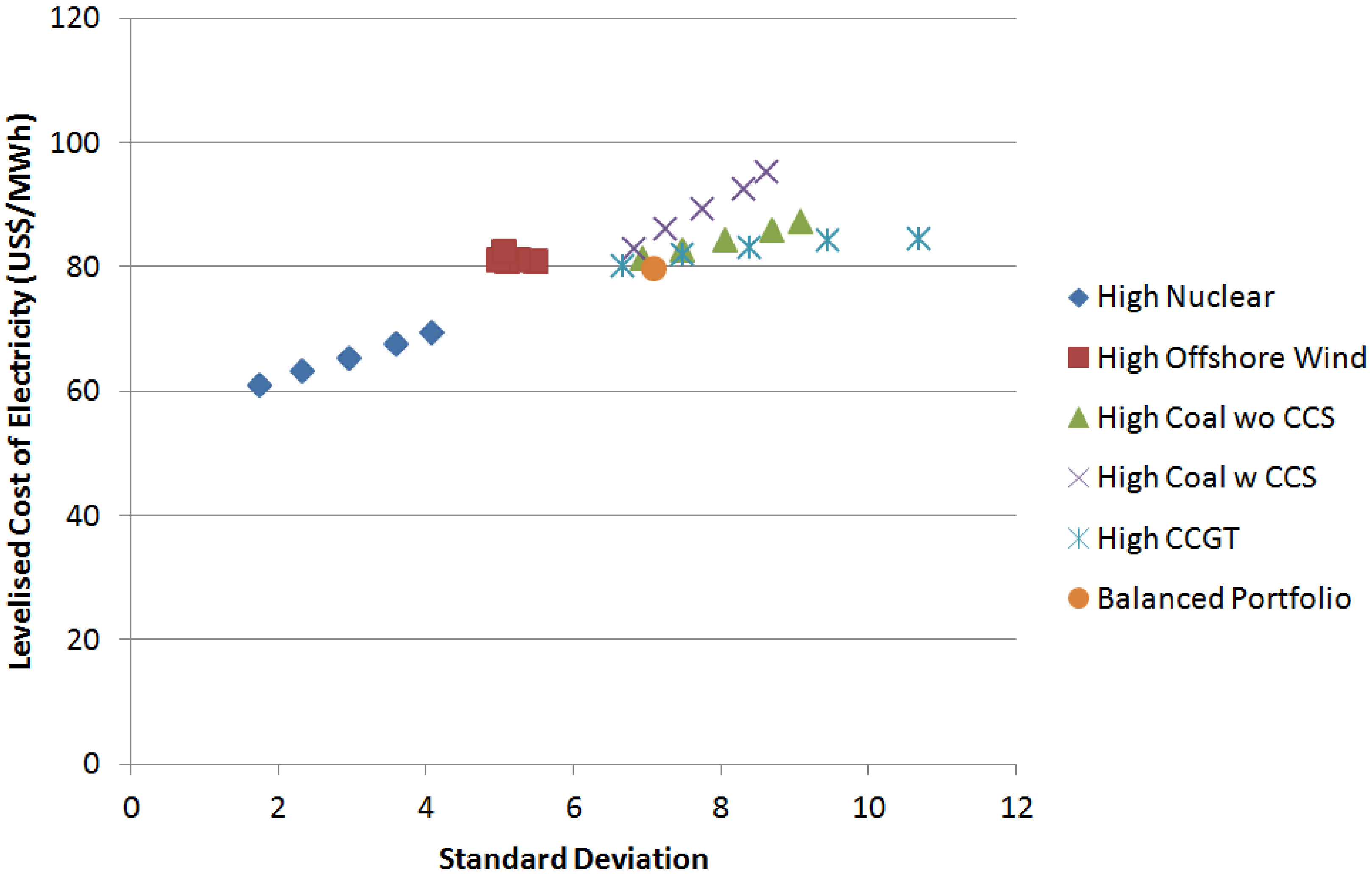
Expected result ?



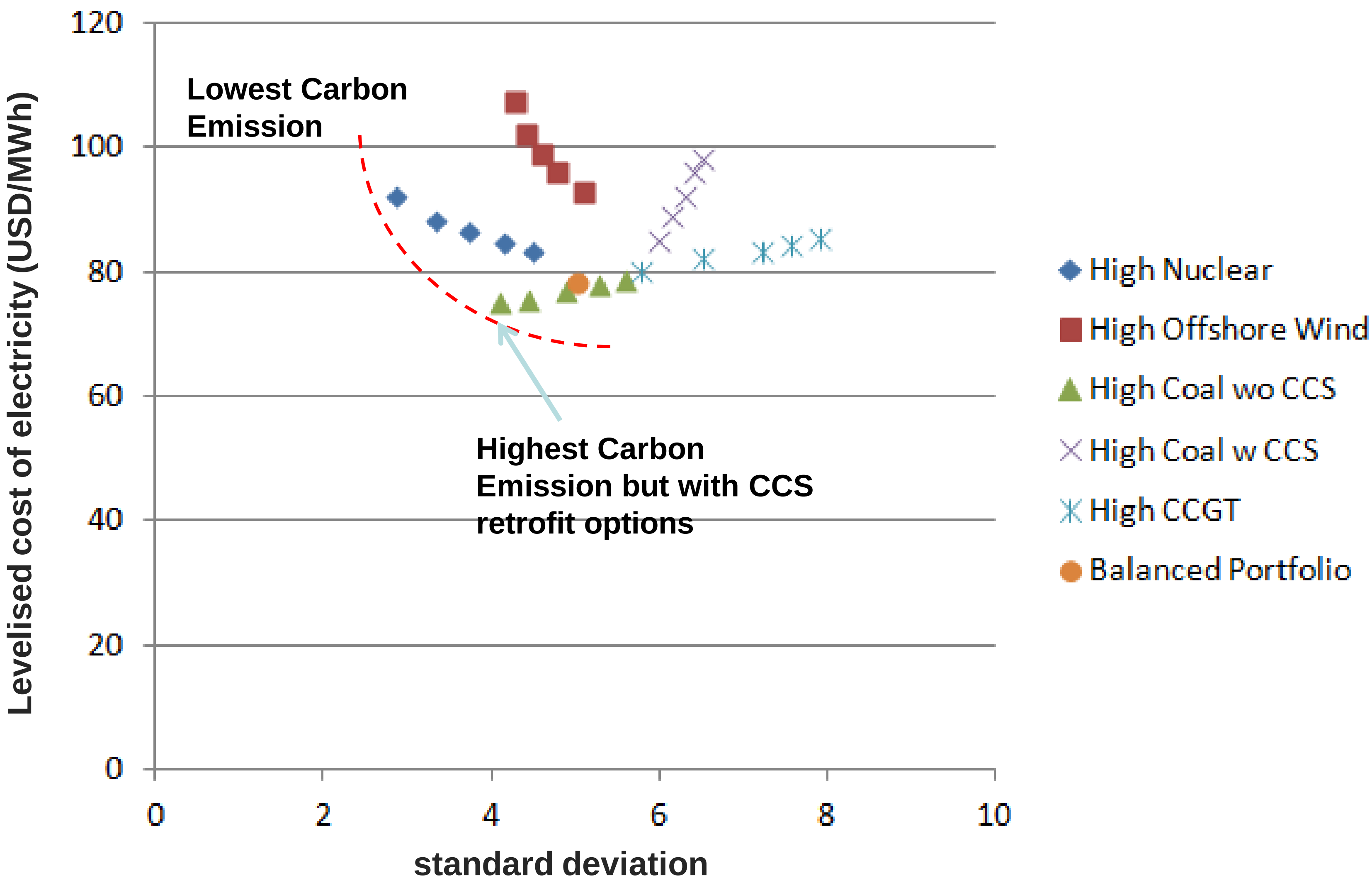
In the mean-variance theory, choose the portfolio option with maximum utility (U), at an investor's risk aversion ratio (A).

$$U = E(r) - 0.5A\sigma^2$$

Estimated the Lifetime Levelised Cost of Electricity and FUEL COST Risk with Different Generation Portfolios <u>without flexibilities</u>



Estimated Value and Risks of the Lifetime Levelised Cost of Electricity with Different Generation Portfolios <u>considering intermittency and flexibility of CCS retrofit</u>



Final Remark

- Energy system through a portfolio approach could take flexibilities of generation technologies and risks into account
- It seems like a rigid ‘efficient frontier’ in the financial market doesn’t exist in this case study, probably due to high ‘entry barrier’ in the energy system, assumptions or modelling limitation
- Nuclear seems to be the most economic option in a traditional deterministic approach, but the economic advantage is not significant if flexibilities of technologies are taken into account
- Coal with CCS is not yet an attractive investment in the generation portfolio but the value of CCS investment flexibilities in unabated coal and unabated gas power plants are significant
- Still a large amount of uncertainties have not yet considered in the study: the impact of existing energy portfolio, technology learning, some technical characteristics, infrastructure and demand side response on investments

Thank you

Implications for Modelling

- **Portfolio**: The energy policy and investment options need to be evaluated at a strategic level through a portfolio approach.
- **Flexibility and Uncertainty**: The real option analysis should be applied to assess the value of flexibilities under uncertainties in the energy system.
- **Optimisation**: Building on the real option analysis framework, a system dynamic approach could be used to optimise the public policy options in the energy system with explicit outcomes and constraints (i.e. low carbon, energy security, affordability, time and budget).
- **Implementation**: A right public policy, which takes into account the future energy policy and technology options, should be prioritised at a right timing to trigger the right investments in the private sector.