Unpacking the Driving Forces of Historical Electricity Generation Cost Change In Korea : Market Forces vs Technological Learning

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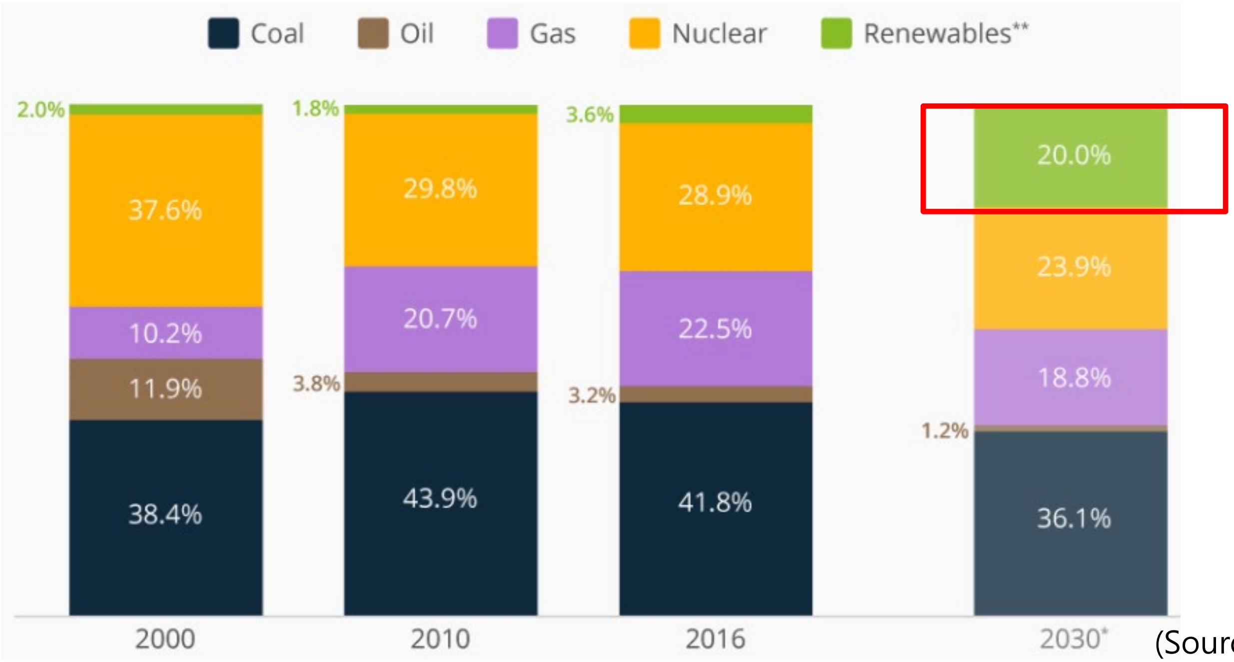
(1) Introduction

- Electricity generation in Korea (9th BPLE*)
  - Promote low-carbon power generation technologies
  - Limiting additional unit of nuclear power plants
  - Conventional power generating sources will remain dominant in 2030



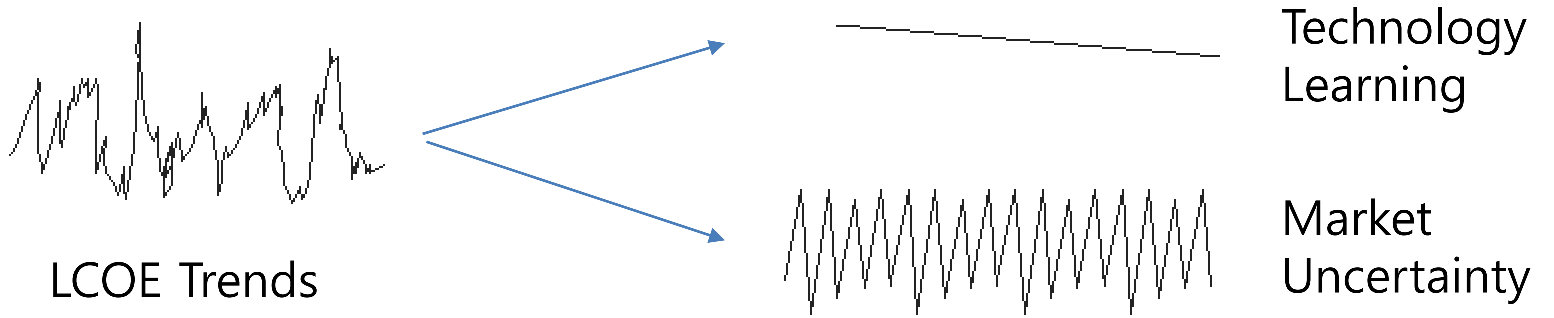
(Source: Buchholz, 2019)

< Electricity generation share by technology in Korea >

* 9th Basic Plan for Long-term Electricity Supply & Demand

(1) Introduction

- Cost of decarbonizing energy system
  - Replacing coal with gas: Reduce emission, Increase volatility of cost
  - Renewable: Costly (up to now), Increase the energy self-sufficiency
- Research Question
  - Will renewable electricity generation likely to become cost-competitive?
  - How technology learning and market uncertainties affect the future LCOE?
  - What are enabling policy, technology, market condition for energy transition?



(2) Literature Review

- LCOE (Levelized Cost Of Electricity)
  - Measure to compare cost-competitiveness of different generation sources
  - Fuel cost, O&M cost, Capital cost are converted in $/kwh unit
- Historical LCOE
  - Decades of empirical plant level cost data: McNerney et al. (2011), Koomey & Hultman (2007), Boccard (2014)
  - Focus on construction cost: Grubler (2010), Lovering et al. (2016)
- Stochastic LCOE
  - Uncertainty in fuel price, carbon price, construction duration, renewable generation
  - Cross technology comparison: Heck et al. (2016), Lucheroni and Mari (2017)
  - In-depth technology analysis: Aldersey-Williams & Rubert (2019), Geissmann & Ponta (2017)
- Contribution
  - Stochastic LCOE projection based on <u>trends & distributions from historical data</u>
  - Cross-technology comparison to draw implications in the <u>context of energy transition</u>

(3) Method

- Data
  - <u>Extensive plant-level data*</u> for conventional technologies (Coal: Steam turbine using bituminous coal, Gas: Combined cycle)
  - Commercial scale renewable plants (Solar >100kW ; Wind >1MW unit)
  - Sources: KITA, EPSIS, KEPCO, KPX, and BNEF

< Data coverage >

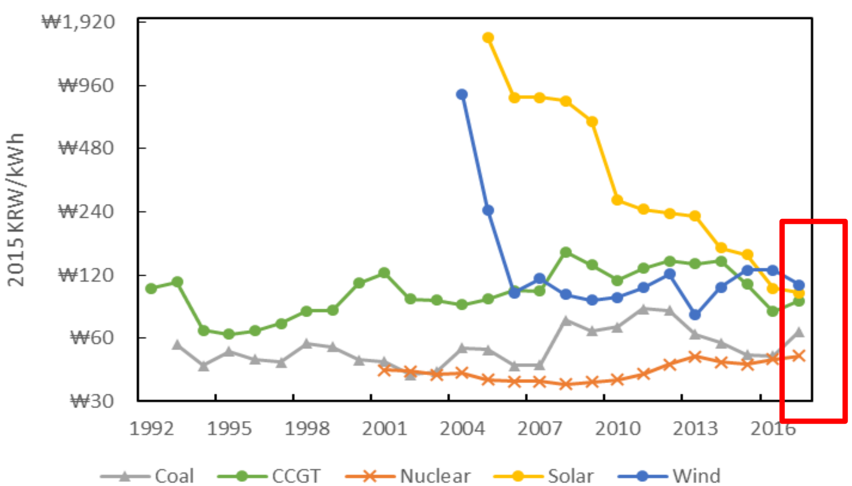
(as of 2019)	**CPP**	**CCGT**	**NPP**	**Solar**	**Wind**
A. Number of plants in operation (GW)	60 (36.9)	187 (32.5)	26 (21.8)	N/A (8.1)	N/A (1.3)
B. Number of plants in analysis (GW)	58 (36.4)	174 (31.0)	26 (21.8)	198 (0.62)	57 (1.14)
Data coverage (B/A)	97.1% (98.6%)	93.0% (95.4%)	100% (100%)	N/A (7.7%)	N/A (87.8%)

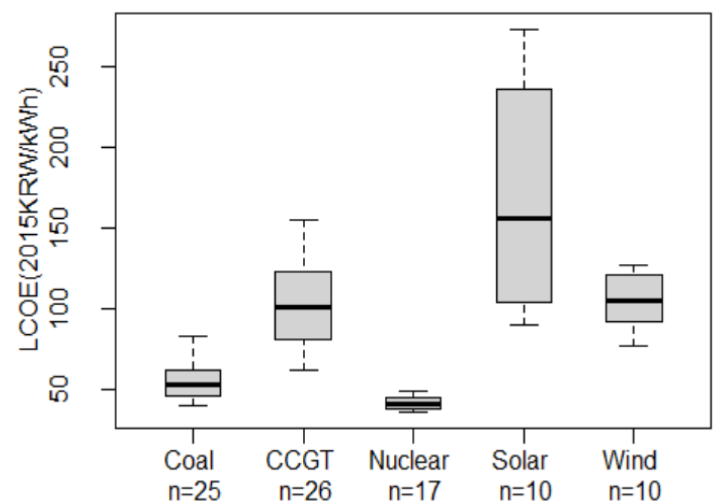
(Source: KPX)

* Plant-level data is limited to construction cost while other data is technology-year-specific

(4) Analysis

- LCOE trends
  - LCOE as of 2017: Nuclear < Coal < CCGT < Solar < Wind
  - Renewable sources are still expensive, but their LCOE is decreasing
- LCOE Volatility
  - LCOE of nuclear is stable while that of fossil-fuel based technologies are volatile
  - <u>LCOE volatility of the CCGT was larger than that of Wind</u>

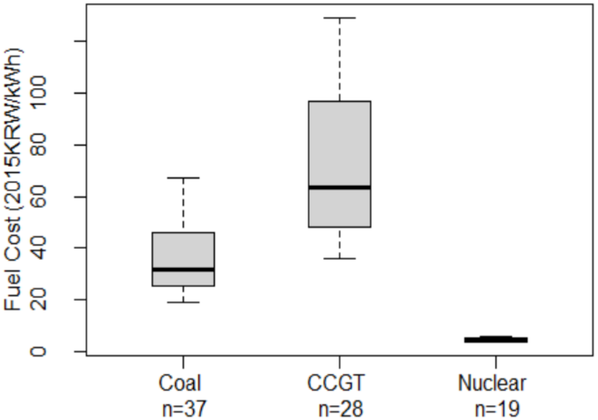




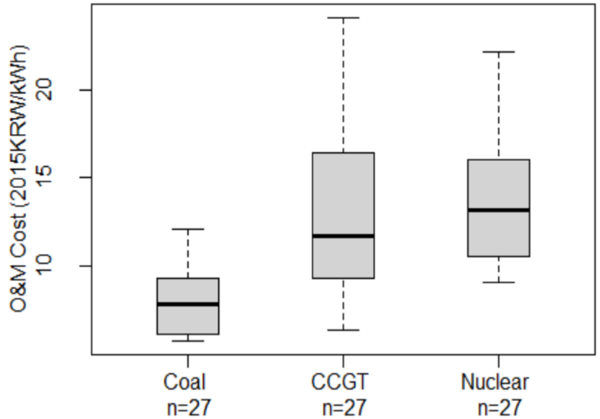
< LCOE trends and volatility of each technology>

(4) Analysis

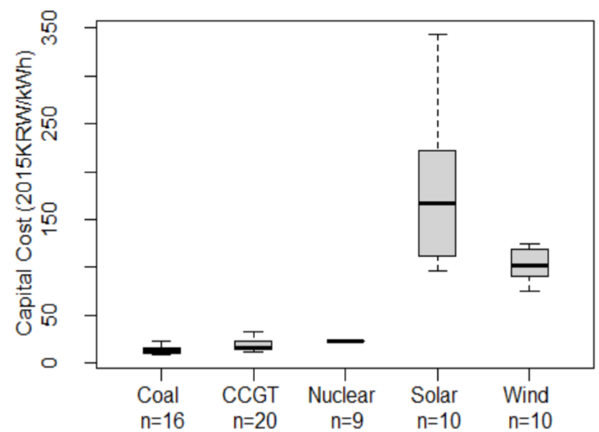
- Source of volatility
  - Fuel cost: Fossil fuel import price (Coal, Gas)
  - O&M cost:
    1) <u>Capacity factor</u> change as a peak-load generator (CCGT)
    2) <u>Increased maintenance</u> due to enhanced safety regulations (Nuclear)
  - Capital cost: Matured technologies show small volatilities while renewables show high volatilities



(a) Fuel cost



(b) O&M cost*



(c) Capital cost

* We could not get representative O&M cost data. We assumed O&M cost is proportional to capital cost for LCOE calculation

(4) Analysis

- Technology Learning
  - Learning rates were derived with construction cost – accumulated capacity
  - Conventional technologies show negative learning
  - Solar technology shows substantial cost decrease while wind did not
- Unit construction cost of CCGT was the lowest while that of solar was the highest in average

< Learning rate of each technology >

	Coal	**CCGT**	**Nuclear**	**Solar**	**Wind**
Period	1984 - 2017	1992-2019	1978 - 2019	2005-2019	2004-2019
Learning rate	-2.23%	**-6.70%	-1.71%	***23.74%	-0.36%
R^2	0.01	0.14	0.03	0.62	0.00
Mean (KRW / kW)	1,380,266	829,673	2,540,236	4,535,774	2,584,806
Standard deviation	330,892	156,964	402,651	3,540,212	716,829

Notes: ***: P < 0.001, **: P < 0.05, *: p < 0.1

(5) Future Projection

- Distribution of key parameters
  - Market factor: derive probability distribution based on historical data*
  - Technology factor: Learning rate
  - Policy factor: Optimal carbon price escalation rate (Peck & Wan, 1996)**

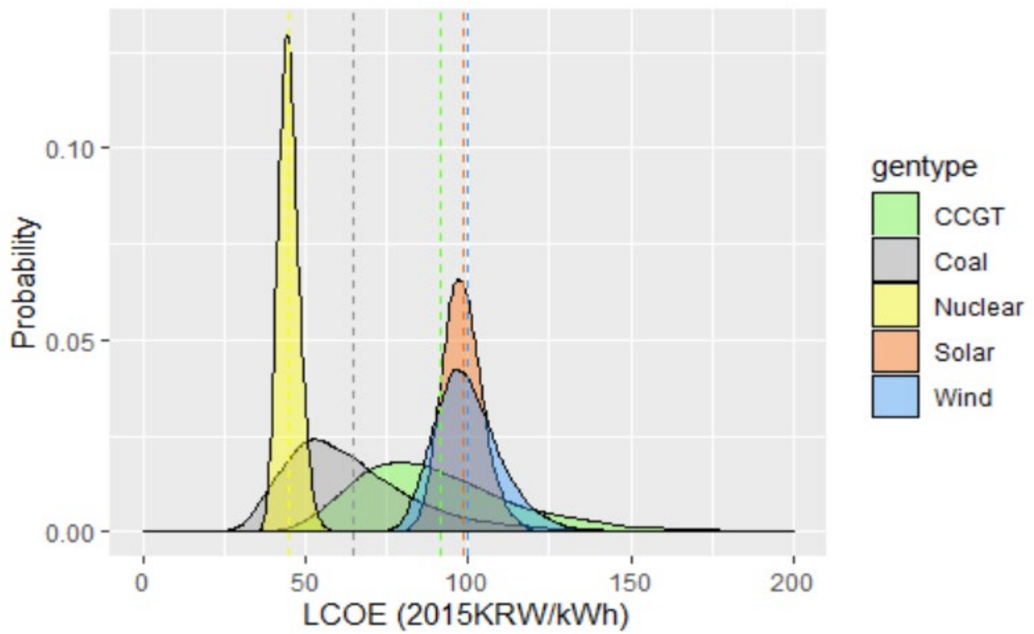
		Conventional			Renewable	
		Coal	CCGT	Nuclear	Solar	Wind
	Life time (years)	40	30	40	25	25
Market factor	Fuel Import Price	**Probability distribution**			N/A	
	Capacity Factor	**Probability distribution**				
	Interest rate	4.5%				
Technology factor	Thermal Efficiency	Historical maximum			N/A	
	Construction cost	**Learning rate & Uniform distribution within a 95% confidence interval**				
	Specific O&M cost	Fixed at the most recent value				
Policy factor	Carbon Price	**Probability distribution**				

* We derive distribution using AD test, Shapiro-Wilcox test, and Kolmogorov-Smirnov test to derive probabilistic distribution

** Carbon price distribution was also derived from the ETS market price with assumed 7% cost escalation in (Peck & Wan, 1996).

(5) Future Projection

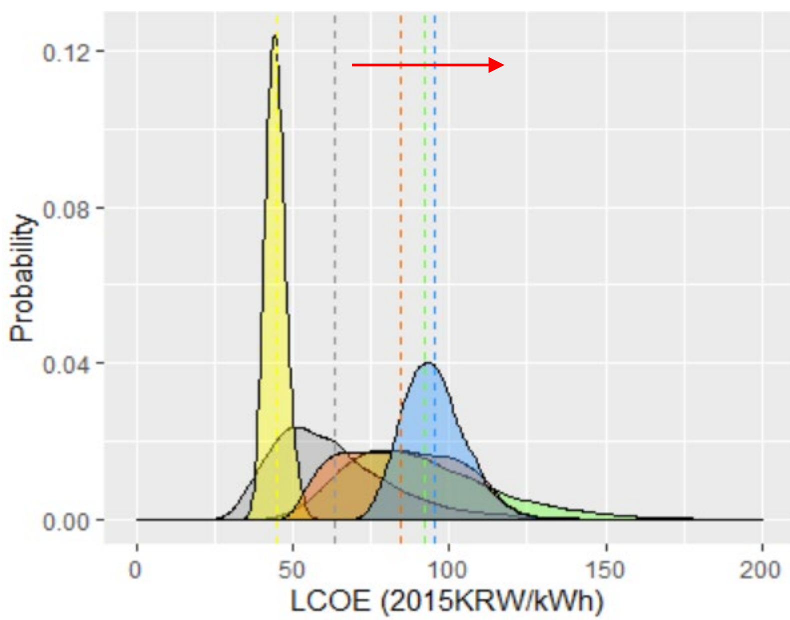
- Monte Carlo Simulation
  - <u>Pair-wise comparison</u> of 10,000 Monte Carlo simulated samples
  - <u>Cost reversal probability</u> (CRP) reveals the probability of one technology become cheaper than the other technology
  ex) CRP (Coal, CCGT) = 18.8% CRP (Coal, Solar) = 7.6%



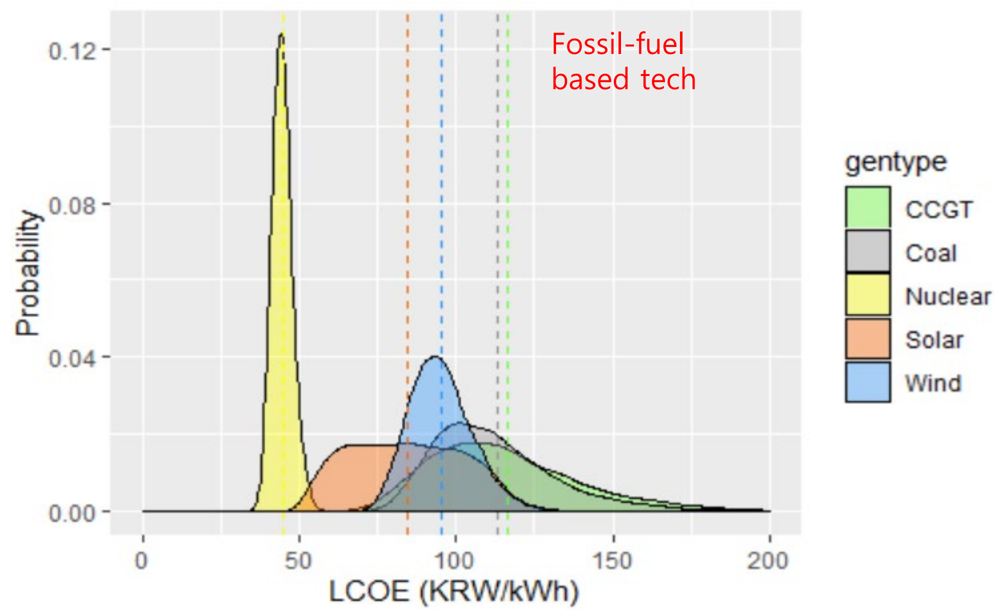
< 2017 LCOE Distribution based on simulation >

(5) Future Projection

- Energy Transition
  - Without policy intervention, solar will become cheaper than CCGT, but remain relatively expensive compared to baseload technology
  ➔ CRP (Coal, Solar) = 20.7% CRP (Coal, Wind) = 9.2%
  - Carbon pricing will relatively make renewables more cost competitive.
  ➔ CRP (Coal, Solar) = 85.2% CRP (Coal, Wind) = 77.6%



(a) 2030 LCOE distribution

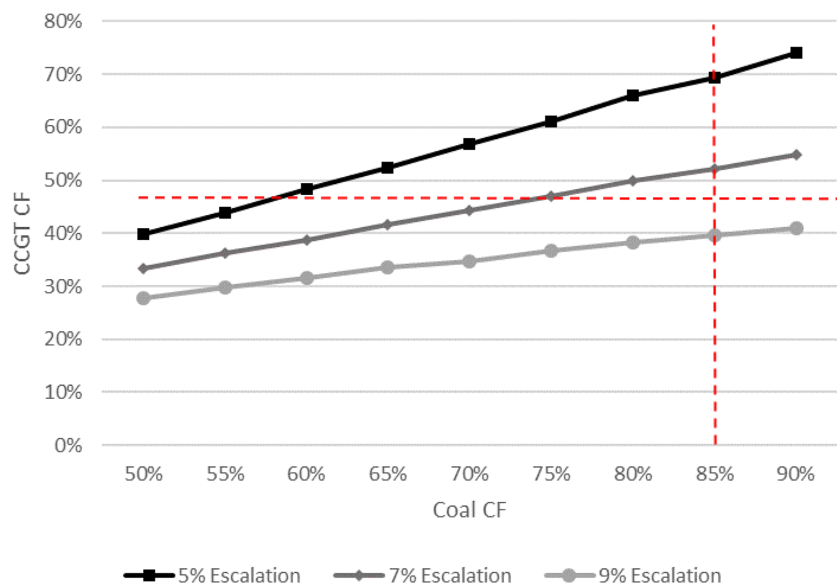


(b) 2030 LCOE with carbon pricing

* The mean carbon price in 2030 is 51,267 KRW/ton (around $46/ton)

(5) Future Projection

- Coal to Gas switching
  - Another strategy to reduce carbon intensity of the energy system
  - If coal keeps current capacity factor (85%), slight increase in CF of CCGT above 50% will make CCGT cost competitive
  - <u>Combination of carbon pricing and increase use of CCGT can phase-out the coal power</u>



< Capacity factor of Coal and CCGT when order change probability is same >

* Dashed line shows the capacity factor of coal and CCGT in 2017, which is 48%

(6) Conclusion

- The change in LCOE of fossil-fuel based power has been accounted for mainly by shifting fuel import prices, while that of nuclear power has been driven primarily by O&M costs.

- No policy measure on the table would keep coal power plants cost-competitive. Carbon pricing is pivotal to accelerate the nation's low-carbon energy transition.

- Transition away from fossil fuel-based power generation decrease the sector's reliance on imported fuel, reducing the overall volatility of power generation cost and promoting the nation's energy security.

- Limitations: We did not consider the potential multivariate relationship between cost parameters and additional system-level costs of renewables arising from the intermittency. Future research would investigate the contribution of these effects

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