The Economic Impact of Nuclear Power Plant Shutdowns

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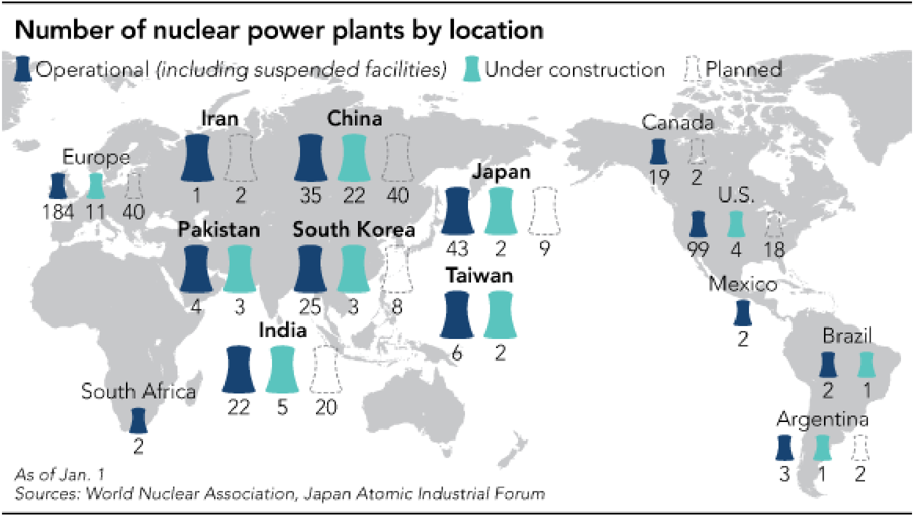
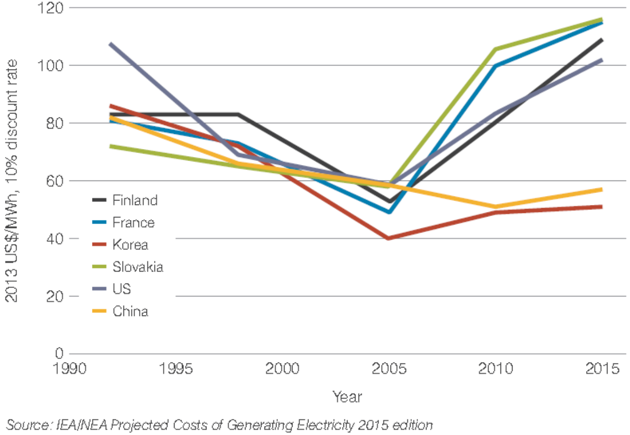
World Nuclear Power Map in 2017



Nuclear Levelised Cost of Electricity (LCOE)



* The LCOE is equivalent to the electricity price needed to cover both the operating and annualized capital costs of the plant and is used as a marker for economic viability.

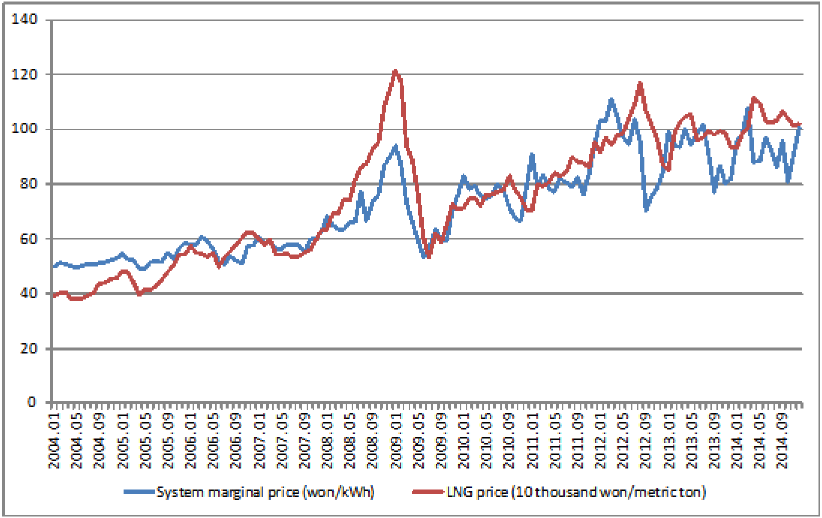
Nuclear Power Generation in Korea

1. Nuclear generation accounts for nearly one-third of South Korea's electricity generation and about 22% of installed generating capacity.
2. South Korea had plans to expand nuclear's share of generation to 60% by 2035. Eleven additional reactors are scheduled for completion by 2029.
3. South Korea intends to reduce its greenhouse gas emission levels by 37% from business-as-usual projected levels (projections of emission levels absent any carbon price scheme) by 2030.
4. Following several scandals related to falsification of safety documentation in 2013, the government shut down reactors temporarily, which removed up to 40% of the nuclear capacity from service until the government inspected all reactors.
5. The new government announced a nuclear phase-out plan over 40 years in May, 2017.

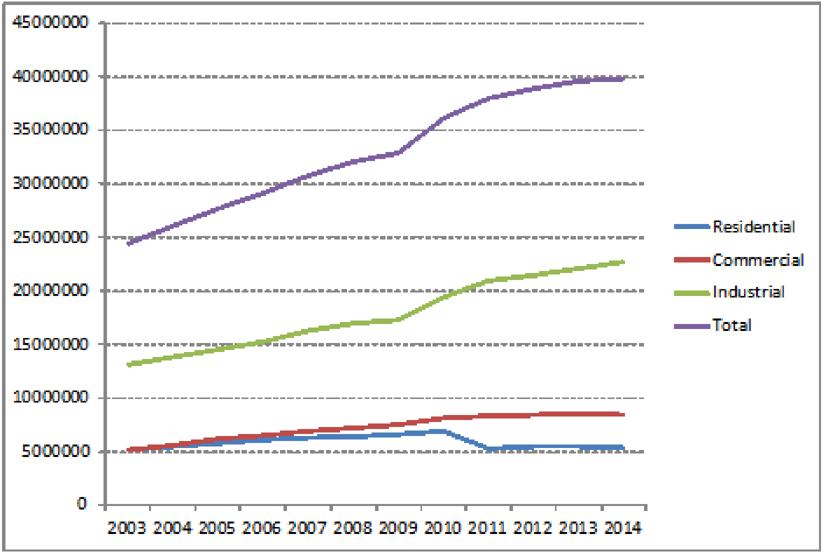
Market Structure

1. Heavily regulated state-enterprise $\Rightarrow$ monopoly in transmission and distribution, major shareholder for 6 generation subsidiaries
2. Hidden cost information $\Rightarrow$ dispute over cross-subsidization
3. Severe increasing block pricing for residential sectors $\Rightarrow$ welfare distortion

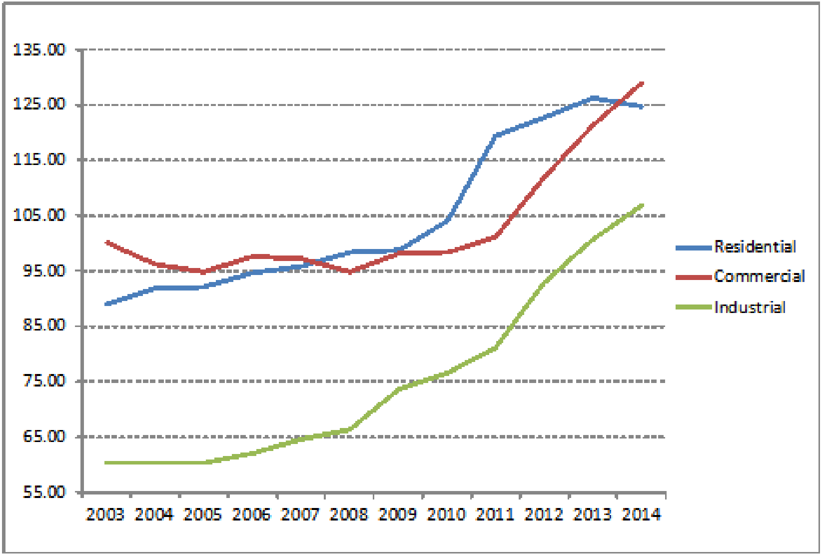
LNG Price versus Wholesale Price



Electricity Sales (GWh)



Sectoral Electricity Prices (1,000 Won/MWh)



Monthly Data from January 2004 to December 2014

- Korea Electric Power Corporation for whole sale price, sectoral retail price, sales revenue, fuel prices, fuel consumption for generation, power reserve rate=(generation capacity-peak demand)/(peak demand)
- Korea Hydro & Nuclear Power Corporation for failed nuclear plants
- Nuclear Safety and Security Commission for scheduled nuclear plant shutdowns
- Constructed Data
  - nuclear plant failure rate = (sum of running generation capacity of each plant)/(maximum capacity of all nuclear plants)
  - green house gas = (fuel consumption for generation) × ($CO2$ emission for fuel types)

Supply Side Equation

Supply side of the electricity retail price equation:

$$p_{it} = \alpha_i + \beta_i q^s_{it} + g_{it} + u_{it},$$

where

- p_{it}: electricity price of the ith sector
- q^s_{it}: electricity supply of the ith sector
- g_{it}: supply-side factor of the ith sector.

Here, $i = 1, 2, 3$ represent residential, industrial, and commercial sectors, respectively, and t is the monthly time index.

(* All values hereafter are in changes or in rate of changes.)

Demand Side Equation

Demand side of the equation:

$$q_{it}^d = \gamma_i + \delta_i p_{it} + \theta_i' x_t^d + v_{it},$$

where

q_{it}^d: electricity demand of the ith sector

x_t^d: explanatory variables for the electricity demand

such as

- consumer price index
- unemployment rate
- heating degree day: the number of degrees that a day's average temperature is below 65° Fahrenheit (18° Celsius)
- cooling degree day: the number of degrees that a day's average temperature is above 65° Fahrenheit

Equilibrium Price

When $q_t^s = q_t^d$,

$$\begin{aligned} p_{it} &= \frac{\alpha_i + \beta_i \gamma_i}{1 - \beta_i \delta_i} + \frac{1}{1 - \beta_i \delta_i} g_{it} + \frac{\beta_i \theta_i'}{1 - \beta_i \delta_i} x_t^d + \frac{u_{it} + \beta_i v_{it}}{1 - \beta_i \delta_i} \\ &= a_i + \tilde{g}_{it} + d_i' x_t^d + e_{it}. \end{aligned} \tag{1}$$

We require both $\tilde{g}_{it}$ and x_t^d to be exogenous to the error term e_{it} to avoid endogeneity problems.

Supply-Side Factors

Supply-side factors (unobserved factors):

$$\tilde{g}_{it} = z_i w_{0t} + w_{it}$$

where

w_{0t}: common factor

w_{it}: idiosyncratic factor of the ith sector

z_i: common factor loading of the ith sector

for $i = 1, 2, 3$

Cost Decomposition & Policy Influence

From equation (1), average retail price is written as

$$\sum_{i=1}^{3} r_i p_{it} = \sum_{i=1}^{3} r_i a_i + \sum_{i=1}^{3} r_i d_i' x_t^d + w_{0t} \sum_{i=1}^{3} r_i z_i + \sum_{i=1}^{3} r_i w_{it} + \sum_{i=1}^{3} r_i e_{it}$$

$$= \tilde{a} + \tilde{d}' x_t^d + \tilde{z} w_{0t} + \sum_{i=1}^{3} r_i w_{it} + \tilde{e}_t.$$

This represents the **revenue** of KEPCO, and each term on the right hand side stands for

- aggregate demand shock ($\tilde{d}' x_t^d$)
- common supply shock ($\tilde{z} w_{0t}$)
- aggregate idiosyncratic supply shock ($\sum_{i=1}^{3} r_i w_{it}$)

except for the constant and error term.

* r_i =(average sales revenue of i-th sector)/(average total sales revenue).

Supply-Side Factor Dynamics

Supply-side factor follows

$$w_{0t} = b_c w_{0,t-1} + c_0' x_t^{sc} + v_{0t},$$
$$w_{it} = b_d w_{i,t-1} + c_i' x_t^{sd} + v_{it}$$

for $i = 1, 2, 3$, where x_t^{sc} is a vector of

- LNG price
- nuclear plant shutdown rate
- (nuclear plant shutdown rate)×(power reserve rate)

and x_t^{sd} is a vector of

- industry production index
- producer price index
- USD/KRW exchange rate

(* The power reserve rates are level data.)

State Space Representation

Measurement equation:

$$p_t = a + \begin{pmatrix} z_1 & 1 & 0 \\ z_2 & 0 & 1 \\ z_3 & -r_1/r_3 & -r_2/r_3 \end{pmatrix} w_t + \begin{pmatrix} 0 \\ 0 \\ \eta_t/r_3 \end{pmatrix} + Dx_t^d + e_t$$

Transition equation:

$$w_t = \begin{pmatrix} b_c & 0 & 0 \\ 0 & b_d & 0 \\ 0 & 0 & b_d \end{pmatrix} w_{t-1} + Cx_t^s + v_t$$

where $p_t = (p_{1t}, p_{2t}, p_{3t})'$, $w_t = (w_{0t}, w_{1t}, w_{2t})'$, $x_t^s = (x_t^{sc}, x_t^{sd})'$, $e_t \sim N(0, R)$, $v_t \sim N(0, Q)$, since

$$w_{3t} = -\frac{r_1}{r_3} w_{1t} - \frac{r_2}{r_3} w_{2t} + \frac{\eta_t}{r_3} + \text{error}$$

Parameter Estimates

Common factor loadings

Residential: 0.40^{**}, Industrial: 0.42^{**}, Commercial: 0.06

Common factor

LNG price:	0.020^{**}
Nuclear plant shutdown:	0.057^{**}
Shutdown×Reserve:	-0.31^{**}

Residential idiosyncratic factor

Industry production index:	-0.29^{**}
Producer price index:	1.04^{**}
Exchange rate:	-0.048^{**}

Industrial idiosyncratic factor

Industry production index:	-0.034
Producer price index:	-0.27^{*}
Exchange rate:	-0.009

Parameter Estimates

Autoregressive coefficients of supply-side factors

Common factor:	0.98^{**}
Idiosyncratic factor:	-0.34^{**}

Residential demand

Consumer price index:	1.05^{**}
Unemployment rate:	-0.0091^{**}
HDD:	0.0005^{**}
CDD:	0.0008^{**}

Industrial demand

Consumer price index:	0.61^{**}
Unemployment rate:	-0.0046^{**}
HDD:	0.0001^{**}
CDD:	0.0002^{**}

(* Estimates with superscript * are statistically significant at the 10% level.)

Impact on Greenhouse Gas Emission

- To investigate the impact of nuclear plant shutdown on greenhouse gas emission, we set up a model as

$$\mathit{green}_t = \tau + \left[\zeta_0 + (\zeta_1 + \zeta_2 \mathit{reserve}_t)\mathit{shutdown}_t\right] q_t^o + e_t, \qquad (2)$$

  where green_t is the change rate of greenhouse gas emission, and q_t^o is the change rate of the total electricity production (without seasonal adjustment).

- This regression model is designed to allow different level of fossil fuel usage depending on the nuclear plant shutdown rate and the power reserve rate.

Parameter Estimates

Quantity equation:

Price elasticity of demand (δ_i)

Residential:	-0.62^{**}
Industrial:	-0.14
Commercial:	-0.03

Price elasticity of supply ($1/\beta_i$)

Residential:	3.98^{**}
Industrial:	5.06^{**}
Commercial:	1.64^{**}

GHG emission model:

$$\tau = -0.0028, \quad \zeta_0 = 1.14^{**}, \quad \zeta_1 = 4.19^{\dagger}, \quad \zeta_2 = -40.32^{**}$$

(* Estimates with superscript * are statistically significant at the 10% level.)

Cross-Subsidization

Define

$$R_i = \frac{\text{Common factor variation}}{\text{Total supply-side factor variation}},$$

i.e., R_i is the ratio of the common factor in the total supply-side factor of each sector. These ratios are calculates as

- $R_1 = 0.021$ (residential)
- $R_2 = 0.12$ (industrial)
- $R_3 = 0.00001$ (commercial).

The prices of residential and commercial sector are more vulnerable to the policy influences than the price of industrial sector.

Cross-Subsidization

For the extreme changes in the demand, there seems to be some cost transfers from residential sector to industrial sector.
For the regression model

$$w_{it} = \textit{constant} + \xi_i \times d_i' x_t^d + \textit{error}_{it},$$

we have estimates as follows:

	Residential		Industrial		Commercial	
	$\hat{\xi}$	(p-value)	$\hat{\xi}$	(p-value)	$\hat{\xi}$	(p-value)
All data	0.59	**(0.342)**	-0.51	**(0.310)**	-0.27	(0.564)
Boundary 20%	1.26	**(0.182)**	-0.60	**(0.125)**	0.32	(0.648)
Boundary 10%	2.40	**(0.107)**	-0.71	**(0.008)**	0.68	(0.439)

Sectoral Price Increase

	Average Price (Won/kWh)	Price Increase (%p)
Residential	$P_1^* = 125$	0.092
Industrial	$P_2^* = 107$	0.096
Commercial	$P_3^* = 129$	0.014

Note: The values are computed when the nuclear plant failure rate increases by 4%p in December 2014, when the power reserve rate is zero.

Consumer Surplus Loss

Total Consumer Surplus Loss: $\$1.47$m per month.

	Consumer Surplus (Won)	Consumer Surplus ($)
Residential	–303 million	–290 thousand
Industrial	–1.19 billion	–1.12 million
Commercial	–72 million	–60 thousand

Note 1: The values are computed when the nuclear plant failure rate increases by 4%p in December 2014, when the power reserve rate is zero.

Note 2: The 2014 average exchange rate is 1,053 won/dollar.

Green House Gas Emission Increase

- From (2),

$$\frac{\partial green_t}{\partial shutdown_t} = (\zeta_0 + \zeta_1 shutdown_t)\frac{\partial q_t^o}{\partial shutdown_t} + \zeta_1 q_t^o$$
$$= -0.0047(\zeta_0 + 0.14\zeta_1) + 0.003\zeta_1 = 0.0045.$$

  Therefore, GHG emission will increase by $4 \times 0.045 = 0.018\%$p a month, when the nuclear plant failure rate increases by 4%p.

- From the 2014 average GHG emission of 16.4 million metric tons a month, the additional increase amounts to 3,000 metric tons a month.

Scenario Analysis

All scenarios starts from the average shutdown rate of 14% in 2014.

- Shutdown Plan 1 (SP1): shutdown rate increases from 14% to 18%, and is fixed at 18% for one year
- Shutdown Plan 2 (SP2): shutdown rate increases from 14% to 26% and is fixed for the first half of the year, and in the second half, the shutdown rate increases and fixed at 38%
- Shutdown Plan 3 (SP3): shutdown rate increases from 14% to 18% in the first month, the shutdown rates in the next 5 months are given by 22%, 26%, 30%, 34% and 38%, respectively, and the rate of 38% is maintained till the end of the year

Scenario Analysis

- Consumer Welfare

	Consumer surplus loss			Price increase		
	Shutdown plans			Shutdown plans		
	SP1	SP2	SP3	SP1	SP2	SP3
Residential	\$21m	\$81m	\$84m	6.62%	25.4%	26.5%
Industrial	\$80m	\$305m	\$320m	6.95%	26.7%	27.8%
Commercial	\$5.1m	\$19.6m	\$20.4m	0.99%	3.81%	3.97%
Total	\$106m	\$406m	\$424m	-	-	-

- Greenhouse Gas Emission

	GHG increase amount	
Shutdown plan	$\delta_1, \delta_2, \delta_3 \neq 0$	$\delta_2 = \delta_3 = 0$
SP1	261 kt	422 kt
SP2	981 kt	1.60 Mt
SP3	1.01 Mt	1.66 Mt